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(BLUE BOOK)

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VOLUME I • SUMMARY

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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REFERENCE EARTH ORBITAL
RESEARCH AND APPLICATIONS INVESTIGATIONS

(Blue Book)

VOLUME I

SUMMARY

15 January 1971

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

PREFACE

The purpose of the preliminary edition of the "Reference Earth Orbital Research and Applications Investigations" set forth in this document is to:

a. Provide criteria, guidelines, and an organized approach for use in the Space Station and Space Shuttle Program Definition Phase and ancillary studies in designing a flexible, multidisciplinary orbiting space facility and logistics system.

b. Define a manned space flight research capability to be conducted in earth orbital Space Stations and Shuttles.

c. Provide a basis for potential follow-on programs.

The term "Functional Program Element" (FPE) used in this document describes a gross grouping of experiments characterized by the following two dominant features:

a. Individual experiments that are mutually supportive of a particular area of research or investigation, and

b. Experiments that impose similar and related demands on the Space Station Support Systems.

The research and applications investigations as set forth herein depart from a heterogeneous collection of individual experiments and are designed toward a "research facility" and "module" approach. The term FPE and "module" are used somewhat interchangeably in this publication although this relationship is unintentional. Thus, a particular FPE may be described which does not fully utilize the capability of a complementary module but would, however, permit flexibility in experiment planning.

Functional Program Elements and experiments covered in this document are envisioned for flight with the initial Space Station and the Space Shuttle. Only those FPE's and experiments which can reasonably be expected to be accomplished during the first few years of the Space Station and Space Shuttle have been described in detail in this document. However, for the most part, these FPE's are considered to be open-ended so that their utility could be extended.

This publication is applicable to all NASA program elements and field installations involved in the Space Station and Space Shuttle program.

The supply of this document is limited. Therefore, for those procurement actions involving only a certain portion (or portions) of this handbook, the cognizant NASA installations shall abstract from this handbook only such portions as apply to a given RFP or contract action.

This publication was prepared in conjunction with NASA Headquarters Program Offices and field installations involved in payload planning and with industry participation. It is an updated and revised version of the Candidate Experiment Program for Manned Space Stations, NHB-7150.xx, dated September 15, 1969 and the changes thereto dated June, 1970. These earlier versions are hereby cancelled.

The material contained in each volume has been produced under the guidance of Review Groups composed of scientific personnel at NASA Headquarters, MSFC, LaRC, MSC, LeRC, GSFC and ARC. The purpose of this effort was not only to revise and update the experiment programs but also to establish the Space Shuttle as well as the Space Station requirements.

Volume I, Summary, presents the background information and evolution of this document; the definition of terms used; the concepts of Space Shuttle, Space Station, Experiment Modules, Shuttle-sortie Operations, and Modular Space Station; and in Section IV, a summary of the Functional Program Element (FPE) requirements is presented.

Volumes II thru VIII contain detailed discussions of the experiment programs and requirements for each discipline. The eight volumes are:

Volume I	Summary
Volume II	Astronomy
Volume III	Physics
Volume IV	Earth Observations
Volume V	Communications/Navigation
Volume VI	Materials Sciences & Manufacturing
Volume VII	Technology
Volume VIII	Life Sciences

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VOLUME I

SECTION 1

INTRODUCTION

SECTION 1

INTRODUCTION

One of the major challenges confronting NASA is the transition from the development of a manned space flight capability to the utilization of that capability for the benefit of our nation and all mankind. The realization of this objective is portrayed in the experiments set forth in the "Reference Earth Orbital Research and Applications Investigations" (Blue Book). This reference experiment program has resulted through an agency-wide effort to define the most beneficial scientific and applications payloads for manned space flight. These payloads in turn provide experiment design criteria and guidelines to guide the design of the Space Station, Space Shuttle, Experiment Modules and other manned space systems designs and operations.

The experiment catalogue established herein is more than just a heterogeneous collection of experiments. It has been developed with the specific intention of describing the facility and support requirements of both experiment groups and the Functional Program Elements (FPEs). The experiments described serve as the basis for development of the total facility requirements and are considered typical and representative of the types of experiments which will be performed in space in the coming decade beginning with the conclusion of the Apollo Program. The document is not to be construed as a commitment by NASA to perform any particular experiment or group of experiments. Instead, the facility requirements approach, which has been used herein and which extends the initial effort in this direction provided by earlier versions of the Blue Book, will provide flexibility for experiment variation and growth, and for the most part, the FPEs can be considered open-ended so their utility can be extended.

1.1 HISTORY AND EVOLUTION

To place this edition of the Blue Book in proper perspective, perhaps it is worthwhile to review the history and evolution of the document. In summer 1968, a number of key people within the various elements of NASA were marshalled into what was then referred to as the Integrated Payload Planning Activity or IPPA. The overall objective of this work was to define reference experiment payloads and activities for each of the major disciplines such as astronomy, biology, etc., and match the experiment program requirements against various space station capabilities and resources such as power, crew time and pointing requirements for use in the manned earth orbital space station program.

Concurrent with the growth of this Integrated Payload Planning Activity, NASA initiated Phase B Space Station definition work. It readily became obvious to those concerned with the experiment definition portion of the IPPA that the experiment programs being developed would be used as the primary experiment program input data to the Phase B

Space Station contractors and also to the Experiment Module contractor. These same data would also be used as the primary guidance for all NASA in-house work related to the experiment program and must therefore proceed on a schedule time-phased with space station definition.

Thus, the initial publication of the Blue Book, dated 1 May 1969, evolved from the experiment portion of the Integrated Payload Planning Activities. The data included in this initial publication was developed between the various NASA headquarters discipline program offices within OMSF, OSSA, and OART; the Payloads Office of the Advanced Manned Mission Program; and MSFC, MSC, and LaRC.

The initial Blue Book was subsequently revised by the Experiment Module Concepts Study contractor, Convair division of General Dynamics (see Figure 1-1). Under Task I of this study the Blue Book provided more experiment and engineering design data. This effort resulted in the publication of the 15 September 1969 Blue Book, which was then supplied to the Phase B Space Station Study contractors.

The space station studies provided several new or revised FPEs which have been incorporated since the 15 September 1969 printing. The rewritten FPEs were:

Biomedical and Behavioral Research

Man/System Integration

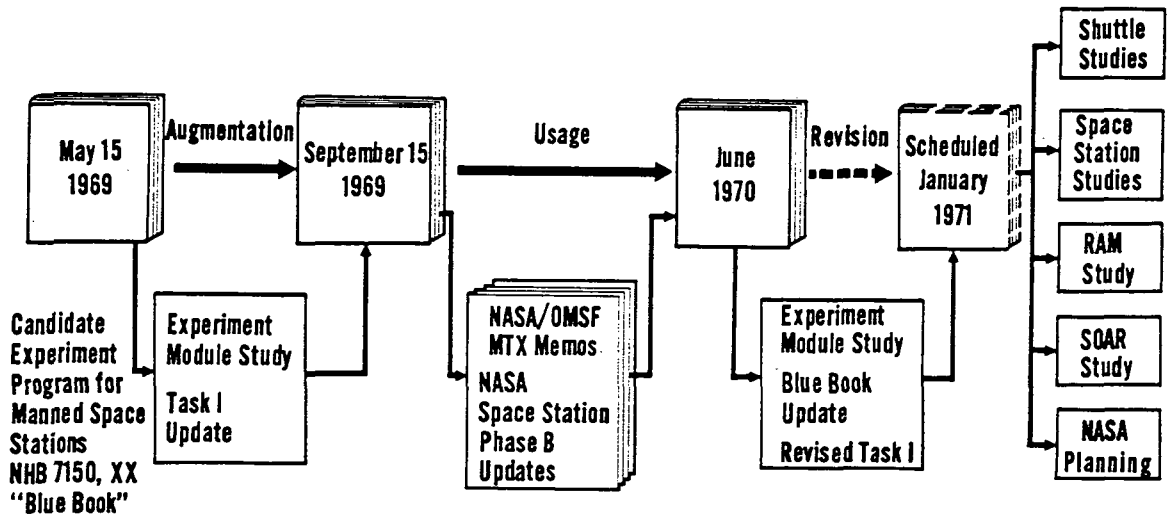


Figure 1-1. Blue Book History and Evolution

Life Support and Protective Systems

Expanded Space Structures

Engineering and Operations

Two additional FPEs were also added:

Primates (Bio A)

Physics and Chemistry Labratory

Addition of these two new FPEs plus the five rewritten FPEs constituted not only the June 1970 edition of the Blue Book, but were used as the baseline experiment program for the Phase B Space Station Studies conducted by the North American Rockwell and McDonnell Douglas Companies under direction by MSC and MSFC respectively.

The June 1970 Blue Book has been used as the point of departure for development of this new document. As shown in Figure 1-1, this update task began in June 1970 and was completed in January 1971. It is intended that this edition be used by NASA as the primary source of experiment program data which will be used in the continuing Space Station studies, Space Shuttle studies, Research Application Module (RAM) studies, and other NASA/MSF experiment planning and utilization studies and activities. These data are thus intended to provide basic design data to identify interface and support requirements for various space vehicle studies. No recommended facility design approaches are intended, although illustrative accommodations are shown for clarification purposes.

Special care should be exercised by the users of this document in utilizing the data presented in Sections Y.5 (Interface Support and Performance Requirements) and Y.6 (Potential Mode of Operation) of each volume. The FPE summary data sheets contained in Section Y.5 represent, in the best judgment of NASA scientists, the overall FPE and experiment requirements to accomplish a realistic experiment program for the total FPE. The rationale for selection of these parameters is in some instances arbitrary but has, as a basis, the total NASA experience and knowledge of prior flight and experiment definition and integration programs. Depending upon how the individual users of these data plan to implement the individual FPE's, the FPE summary sheet data may vary according to special circumstances. Furthermore, the summary data portrayed on these sheets is not intended to imply that the total FPE must be accomodated as an integral unit. The implementation of portions of these FPE's at different times should be considered by the users, depending on the case in question and the particular FPE under consideration.

The information presented in Y.6 (Potential Mode of Operation) is "food for thought" only, and is subject to acceptance or rejection by the Blue Book user. The user must often perform major trade studies to make the final determination of the mode of operation or accommodation.

1.2 PURPOSE OF THIS UPDATING

The purpose of updating the June 1970 Blue Book was to improve the quality of the experiment requirements data for the continuing NASA Space Station and Space Shuttle and RAM definition activities. In updating the Blue Book the following points were considered:

- The Blue Book dated June 1970 was incomplete and obsolete in some areas.
- It should reflect both Space Shuttle and Space Station payload requirements.
- Additional engineering design data was required.
- Additional data was needed to support mission payload planning and simulation activities.
- It should reflect most up-to-date requirements for potential "users".
- Discrepancies in Space Station Phase B contractor's interpretation of data had to be rectified.

To accomplish this updating activity an intra-agency management structure was organized (Figure 1-2). The purpose of using this type of management structure was to bring together the special expertise from all the elements of NASA for each major discipline to ensure that each FPE within each discipline area was developed in accordance with overall agency and "potential user" requirements. During the update, each review group again interfaced directly with the appropriate NASA Headquarters program office to ensure that all scientific requirements were properly described.

1.3 BLUE BOOK CONTENTS AND LOCATION OF DATA

The contents of this edition of the Blue Book and the location of the information is portrayed on Figure 1-3. Volume I, Sections 1 - 4, which is a summary of the overall Blue Book, contains that information of a general nature applicable to all disciplines. Since it is anticipated that some of the Blue Book users will not be familiar with the potential Space Station and Space Shuttle programs, a summary is presented in Section 3 for their orientation. Included in Section 4 are summary data for each FPE. This section is intended for use as a quick reference information source from which many of the principal FPE requirements may be extracted.

Volumes II through VIII contain the detailed information for each FPE and each experiment as noted in Figure 1-3.

1.4 DISCIPLINES WITH FPE's

The following is a listing of the seven Blue Book disciplines and the FPE's within these disciplines. So that all users of this information will refer to them in a consistent manner, a suggested abbreviation system is shown in parentheses.

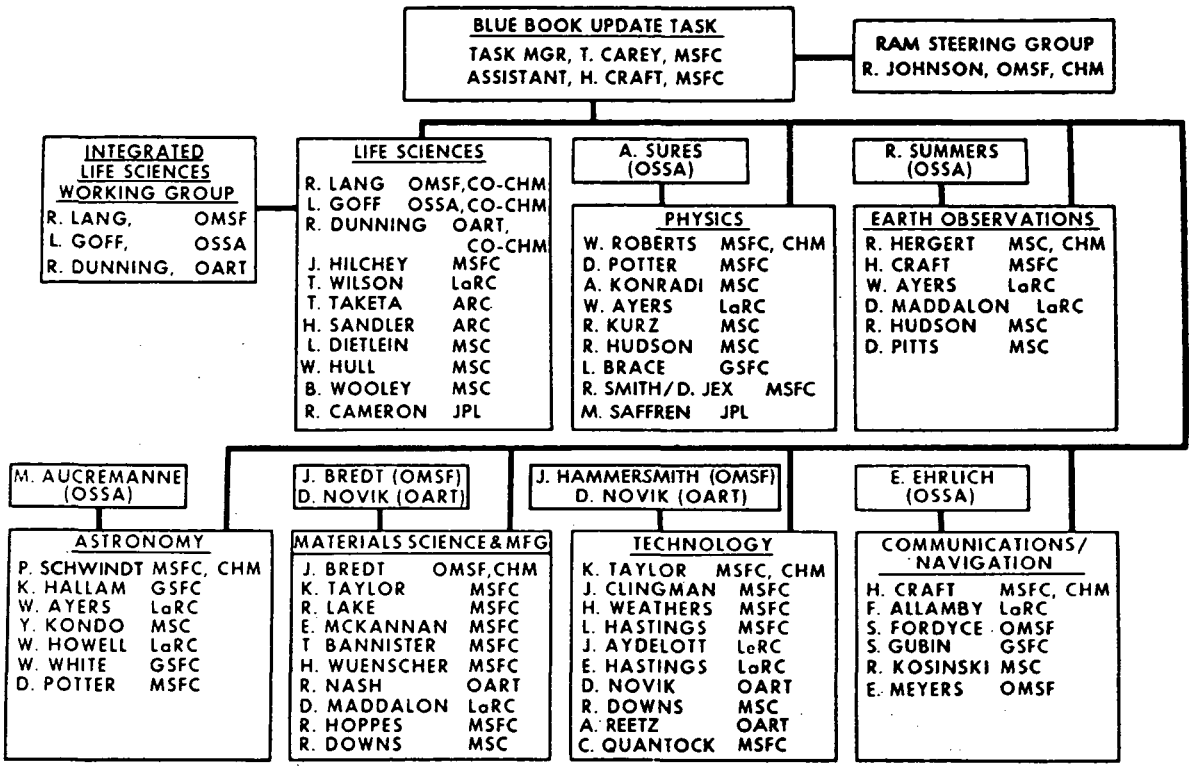


Figure 1-2. Blue Book Update NASA Review Group Structure

Astronomy

X-Ray Astronomy (A-1)

Advanced Stellar Astronomy (A-2)

Advanced Solar Astronomy (A-3)

Intermediate Size UV Telescopes (A-4)

High Energy Stellar Astronomy (A-5)

IR Astronomy (A-6)

Physics

Space Physics Research Laboratory (P-1)

Plasma Physics and Environmental Perturbations Laboratory (P-2)

Cosmic Ray Physics Laboratory (P-3)

Physics and Chemistry Laboratory (P-4)

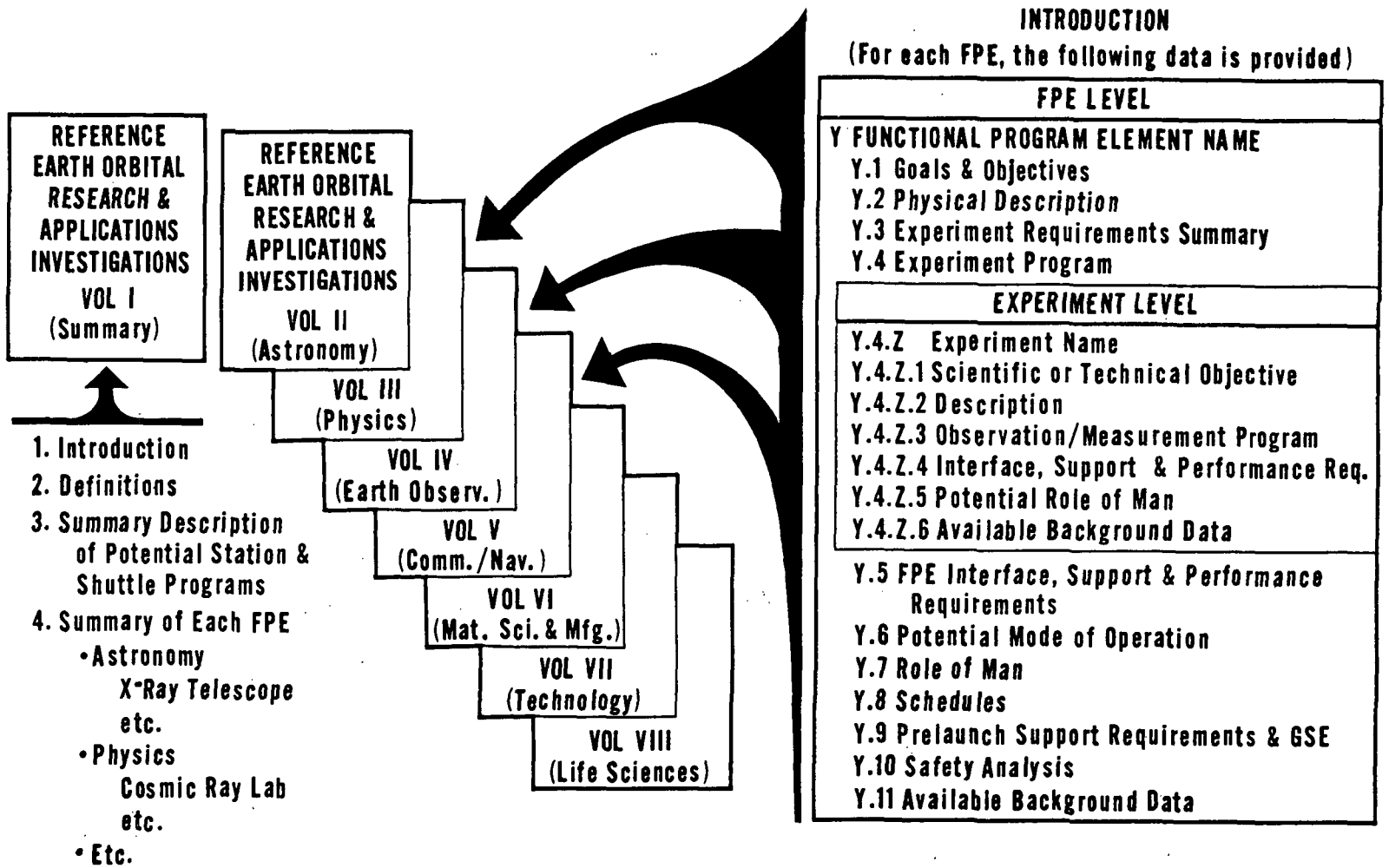


Figure 1-3. NASA Blue Book Contents

Earth Observations

- Earth Observations Facility (ES-1)

Communications/Navigation

- Communications/Navigation Research Facility (C/N-1)

Materials Science and Manufacturing

- Materials Science and Manufacturing in Space (MS-1)

Technology

- Contamination Measurements (T-1)
- Fluid Management (T-2)
- Extravehicular Activity (EVA) (T-3)
- Advanced Spacecraft Systems Tests (T-4)
- Teleoperations (T-5)

Life Sciences

- Medical Research Facility (LS-1)
- Vertebrate Research Facility (LS-2)
- Plant Research Facility (LS-3)
- Cells and Tissues Research Facility (LS-4)
- Invertebrate Research Facility (LS-5)
- Life Support and Protective Systems (LS-6)
- Manned System Integration (LS-7)

1.5 SYSTEM OF UNITS

This edition of the Blue Book, in keeping with NASA Policy Directive NMI 2220.4 dated September 14, 1970, has all values expressed in SI units (Systeme International d' Unites*). However, in order not to reduce the usefulness of this document, expression of units is in both SI units and the customary English system. The SI units are stated first and the customary units afterwards in parentheses. It should be noted that the physical quantities derived in the Blue Book are in the SI system. The equivalent value shown in the English system is an approximation. Table 1-1 is a list of the names of the SI units and dimensions.

1.6 BACKGROUND DATA

The major sources of experiments and engineering data contained in this edition of the Blue Book were the following:

1. Earth Orbital Experimental Program and Requirements Study, McDonnell-Douglas Corporation, NAS 1-9464.

2. Space Station Program Definition Phase B, McDonnell-Douglas Corporation, NAS 8-25140.

3. Space Station Program Phase B Definition, North American Rockwell, NAS 9-9953.

4. Experiment Module Concepts Study, Convair division of General Dynamics, NAS 8-25051.

5. Experiment Program for Extended Earth Orbital Missions, [Revision No. 1 to the "Experiment Program for Manned Orbital Workshops", 14 August 1968] 1 September 1969, Payloads Directorate, Advanced Manned Missions Program, Office of Manned Space Flight.

*This system of units is defined in NASA Publication SP-7012 dated 1969. The reader is referred to this publication for a complete definition of these units.

Table 1-1. Names of International Units

PHYSICAL QUANTITY	NAME OF UNIT	SYMBOL	
	BASIC UNITS		
Length	meter	m	
Mass	kilogram	kg	
Time	second	s	
Electric current	ampere	A	
Temperature	kelvin	K	
Luminous intensity	candela	cd	
	DERIVED UNITS		
Area	square meter	m^2	
Volume	cubic meter	m^3	
Frequency	hertz	Hz	(s^{-1})
Density	kilogram per cubic meter	kg/m^3	
Velocity	meter per second	m/s	
Angular velocity	radian per second	rad/s	
Acceleration	meter per second squared	m/s^2	
Angular acceleration	radian per second squared	rad/s^2	
Force	newton	N	($kg\text{-}m/s^2$)
Pressure	newton per sq meter	N/m^2	
Kinematic viscosity	sq meter per second	m^2/s	
Dynamic viscosity	newton-second per sq meter	$N\text{-}s/m^2$	
Work, energy, quantity of heat	joule	J	(N-m)
Power	watt	W	(J/s)
Electric charge	coulomb	C	(A-s)
Voltage, potential difference, electromotive force	volt	V	(W/A)
Electric field strength	volt per meter	V/m	
Electric resistance	ohm	Ω	(V/A)
Electric capacitance	farad	F	(A-s/V)
Magnetic flux	weber	Wb	(V-s)
Inductance	henry	H	(V-s/A)
Magnetic flux density	tesla	T	(Wb/m^2)
Magnetic field strength	ampere per meter	A/m	
Magnetomotive force	ampere	A	
Luminous flux	lumen	lm	(cd-sr)
Luminance	candela per sq meter	cd/m^2	
Illumination	lux	lx	(lm/m^2)
Wave number	1 per meter	m^{-1}	
Entropy	joule per kelvin	J/K	
Specific heat	joule per kilogram kelvin	$J\ kg^{-1}\ K^{-1}$	
Thermal conductivity	watt per meter kelvin	$W\ m^{-1}\ K^{-1}$	
Radiant intensity	watt per steradian	W/sr	
Activity (of a radioactive source)	1 per second	s^{-1}	
	SUPPLEMENTARY UNITS		
Plane angle	radian	rad	
Solid angle	steradian	sr	

VOLUME I

SECTION 2

DEFINITIONS

SECTION 2

DEFINITIONS

The terminology and definitions used in the current Blue Book reflect an approach involving the use of dedicated laboratories or facilities for the support of various scientific disciplines.

Discipline — A basic scientific or technical field, as:

Astronomy

Physics

Earth Observations

Communications/Navigation

Materials Science and Manufacturing

Technology

Life Sciences

Functional Program Element (FPE) - A grouping of experiments, experiment classes, or research activities characterized by being mutually supportive of a particular dicipline of research or investigation or by imposing similar and related demands on the support systems.

Facility - A group of equipment and instrumentation required for performance of the experiment class described in an FPE.

Laboratory - A laboratory may be made up of the facility requirements of one or more FPEs or partial FPEs. Commonality of equipment is one criterion for grouping facilities of FPEs of different disciplines into the same laboratory. Total laboratory definition is generally left to the system designer.

Experiment Class - A broad category of experiments within a discipline and FPE which scopes the general area of research and the facility requirements in that area.

Experiment - A typical scientific or technical investigation utilizing some (or all) of the equipment included in a facility.

Modes of Accommodation - The means by which an FPE and associated experiments are accomplished.

Space Shuttle - A reusable manned spacecraft whose mission is either to resupply a space station with additional crewmen, supplies and experiments or to carry men, supplies and experiments into orbit, support them for periods ranging from 7 to 30 days, and return them to earth. The shuttle also has the capability to deliver unmanned satellites into orbit, and recover cooperative and noncooperative satellites.

Space Station - A large orbital facility capable of supporting large numbers of men over periods of several years. The space station of the 1980's will be a broad-based, multi-disciplinary research facility able to accommodate a wide variety of advanced and sophisticated experimentation and research modules, together with the associated scientists and investigators.

Experiment Module - A laboratory or experimental facility containing propulsion, power, control, and support equipment to comprise an integral unit. The module may operate in conjunction with other vehicles, such as a Space Station (attached) or a Shuttle (Shuttle-sortie), or it may operate alone in the free-flight mode (detached).

Shuttle-Sortie Mode - For various reasons it may be necessary or desirable to perform experiments using an experiment module and the Shuttle only; i.e., without the support of the Space Station. In the Shuttle-sortie mode, the experiment module would be carried into orbit by the Shuttle. The Shuttle would stay in orbit while the experiments were being conducted, and then return the module to earth.

VOLUME I

SECTION 3

SUMMARY DESCRIPTION OF SPACE STATION AND SPACE SHUTTLE PROGRAM

SECTION 3

SUMMARY DESCRIPTION OF SPACE STATION AND SPACE SHUTTLE PROGRAM

3.1 INTRODUCTION

This section deals with the current concepts and thinking within NASA as to the various approaches which may be taken to performing manned earth orbital experimentation. None of the concepts presented are approved concepts but indicate possible approaches to orbiting spacecraft designs and transportation from earth to orbit and return.

The brief descriptions following are presented only to acquaint the reader with potential systems rather than to spell out definitive space programs which are still in the throes of conception, definition and development.

The order of presentation does not imply any preferential order of importance or emphasis. The Space Shuttle is discussed first to provide the background on the transportation system required to: (1) supply and service the Space Station, (2) deliver Experiment Modules to the Space Station, (3) transport modules to orbit for the buildup of a modular Space Station, (4) carry Experiment Modules into orbit, conduct experiments and return to earth in what is known as the Shuttle-sortie concept, and (5) accomplish a multitude of other tasks such as delivery of unmanned spacecraft and retrieval of cooperative and noncooperative satellites.

3.2 SPACE SHUTTLE

The operational date currently anticipated for the Space Shuttle is late 1977. The general arrangement of the Space Shuttle concept is depicted in Figure 3-1. The Space Shuttle is a fully reusable two-stage vehicle with a liftoff weight of 1.6×10^6 kg (3.5 million pounds). Launch trajectory design load factors are 4 g, reducible to 3 g for passenger transport. It is assumed that launch sites are at KSC and the Western Test Range (WTR). The Space Shuttle is capable of all-azimuth launch, and minimum assembly and checkout are required on the pad. Its mission active duration is seven days but can be extended to 30 days by drawing expendables from additional equipment which would be located in the payload bay. A useful life of 100 flights is assumed.

The Space Shuttle is designed to lift off within a 60-second launch window; it is capable of accomplishing rendezvous with any low-altitude manned satellite in less than 24 hours. For rapid-response operations (rescue), the Space Shuttle is capable of launch from a standby status within two hours.

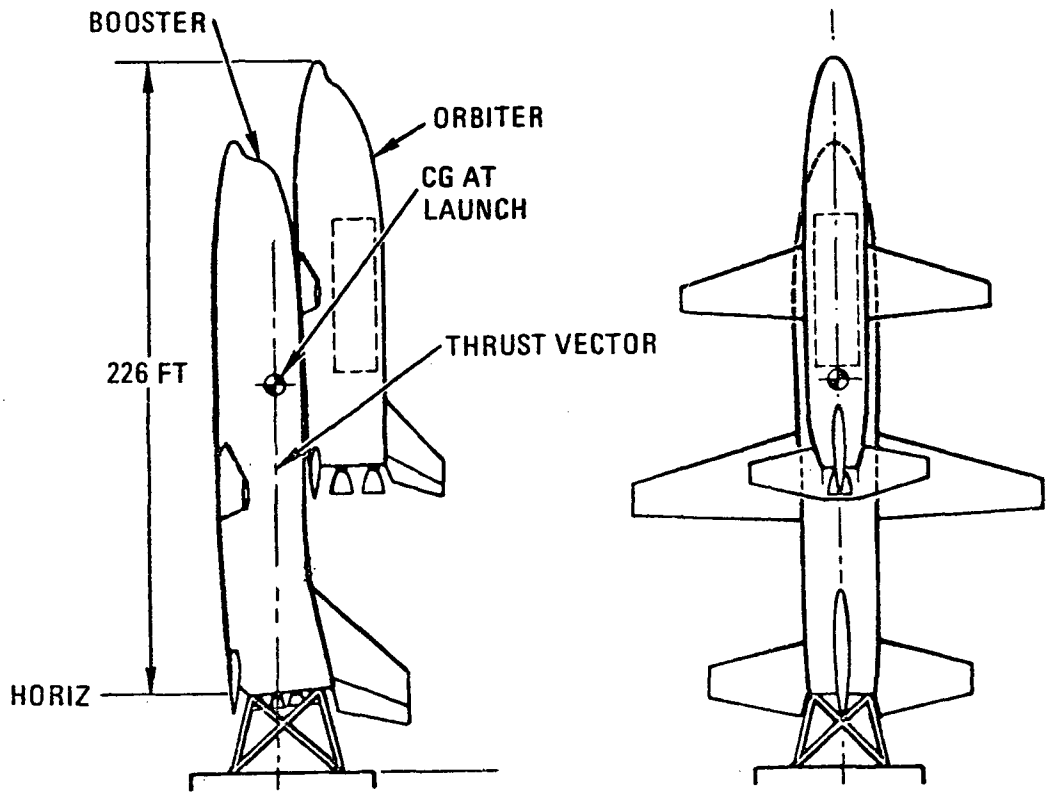


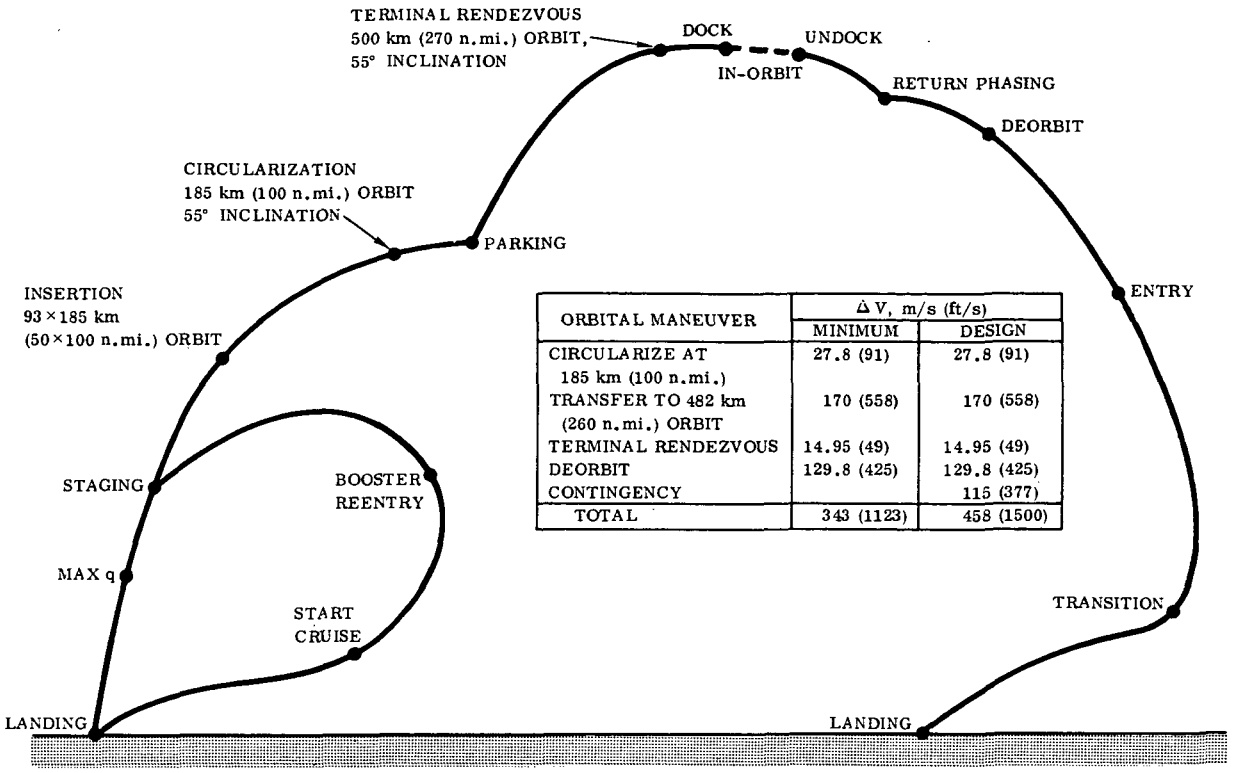
Figure 3-1. Space Shuttle Launch Concept

Rendezvous with a passive target such as an unmanned Space Station or detached Experiment Module also is within its capability, using ground and on-board equipment. Figure 3-2 presents the Space Shuttle flight profile for the baseline mission. On-orbit active stay time is five days (maximum); in a quiescent mode, the Space Shuttle may be able to stay on orbit for 30 days.

The Space Shuttle orbiter inboard profile is shown in Figure 3-3. The payload bay is 4.6 meters (15 feet) in diameter and 18.3 meters (60 feet) long.

As noted in Figure 3-3, the Space Shuttle has an internal sealable tunnel with a standard interface between the crew compartment and the payload bay. Limited cargo transfer also is possible through the personnel transfer hatch immediately adjacent to the crew compartment.

Supporting the modules in orbit requires the same rendezvous and docking operation as with the station in its unmanned phase. In some cases, however, the Space Shuttle will be called upon to retrieve the modules and return them to the station for service or storage.



ORBITAL MANEUVER	ΔV, m/s (ft/s)	
	MINIMUM	DESIGN
CIRCULARIZE AT 185 km (100 n.mi.)	27.8 (91)	27.8 (91)
TRANSFER TO 482 km (260 n.mi.) ORBIT	170 (558)	170 (558)
TERMINAL RENDEZVOUS	14.95 (49)	14.95 (49)
DEORBIT	129.8 (425)	129.8 (425)
CONTINGENCY		115 (377)
TOTAL	343 (1123)	458 (1500)

Figure 3-2. Space Shuttle Flight Profile

The Space Shuttle would dock a new module, transfer the passengers, undock and fly around to the other module loaded with down-cargo, dock with it, disengage it from the station, and await return phasing. In this type of operation, rest time for the Shuttle flight crew would constitute the time the Shuttle is actually attached to the station. Figure 3-4 depicts this mode of operation.

3.3 SPACE STATION

As a long-lasting, general-purpose facility in Earth orbit, the Space Station will be used to provide means of surveying Earth resources as well as to support the scientific disciplines of Astronomy, Life Sciences, Material Science and Manufacturing, Space Physics, Communications and Navigation, and Advanced Technology. The Space Station will also play a major role in the development of future space systems and operations. Its design, therefore, is dominated by the need to accommodate a broad spectrum of activities that may change markedly over the years. Thus, versatility and maximum exploitation of man's adaptability and talent for decision-making are design keynotes. It is vitally important that the Space Station be applicable to a wide range of requirements in order to serve the needs of a variety of different users.

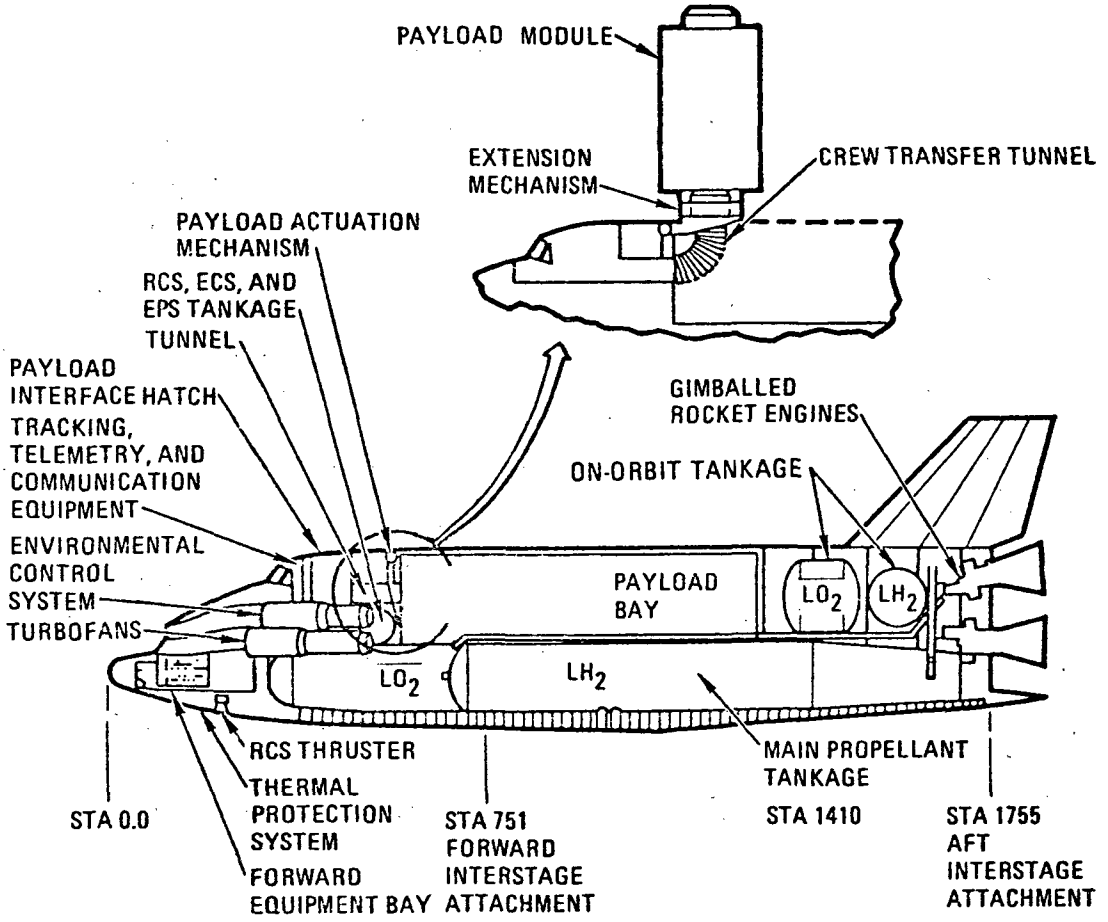


Figure 3-3. Space Shuttle Orbiter Inboard Profile

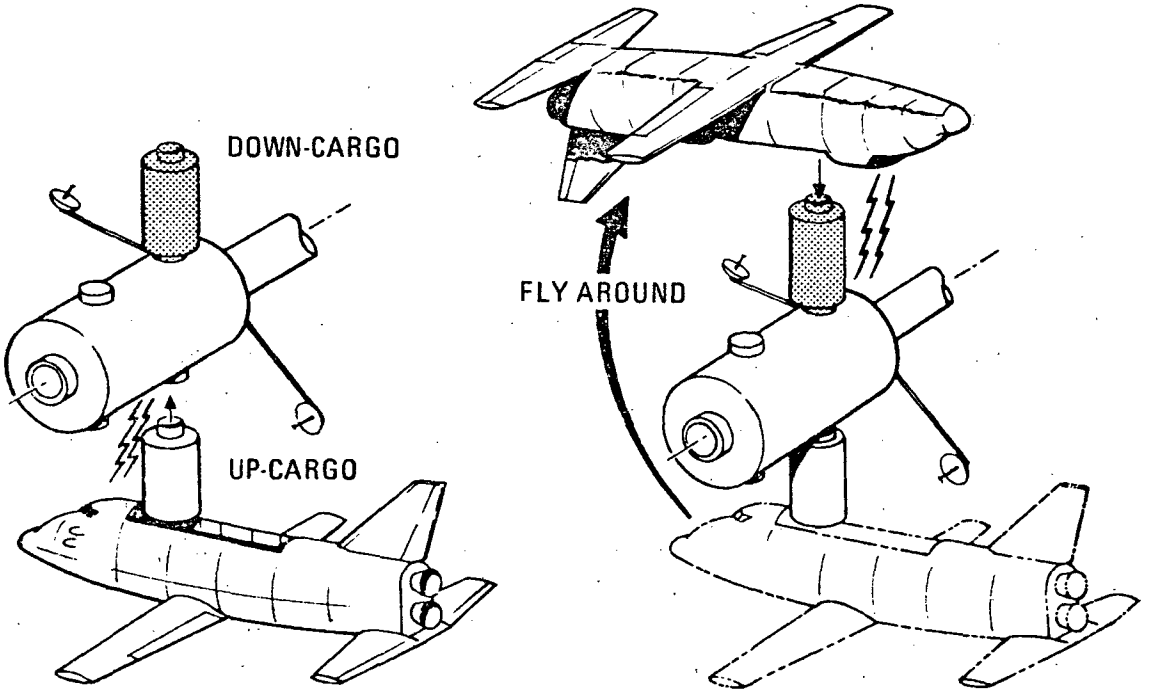


Figure 3-4. Cargo Module Operational Mode

Two basic approaches are currently being pursued toward development of the Space Station: The Integral Space Station, wherein the basic element is a core module launched on a large launch vehicle, and the Modular Space Station wherein the station is launched by the Shuttle and subsequently assembled in orbit. These two approaches are described in the following subparagraphs.

3.3.1 INTEGRAL SPACE STATION. The Integral Space Station will be launched into a circular 500 km (270 n.mi.) 55-degree-inclination orbit that affords good coverage for Earth observations. Once the Integral Space Station is in orbit, its operations will be largely autonomous, making an extensive ground support complex unnecessary. It will have facilities for a crew of 12 and will be placed in orbit with the Intermediate-21 launch vehicle.

Resupply and crew rotation will require an average of four Earth-to-Station round-trip flights per year. After each of these flights, the Integral Space Station will have sufficient reserves to operate for 180 days. Crew and cargo will be carried in a module transported into orbit by the Space Shuttle. On return flights, the Shuttle will transport data from the experiment program, returning crewmen, and wastes, all housed in the crew/cargo module. Experiment modules will be delivered to the station as required.

The basic element of the Integral Space Station System is the core module. This module is a structural assembly fitted with equipment for environmental control, crew support, and power distribution. Structurally, it consists of an external cylinder 10 meters (33 feet) in diameter, an internal cylinder that forms a tunnel 3.05 meters (10 feet) in diameter, and a torodial closure on each end.

One concept of the Integral Space Station core module (Figure 3-5) consists of two sections connected by a 10-meter (33-foot) diameter skirt and a tunnel section, an outer meteoroid bumper and radiator shell, a power and equipment section located at the forward end, and a skirt at the aft end.

Each section is divided into two decks containing laboratory facilities on one deck and crew quarters for six men on the other. In an emergency, either section can accommodate the entire 12-man crew, as can the tunnel. A conceptual arrangement of the Integral Space Station with provisions for the experiment areas and crew quarters is shown in Figure 3-6.

Of the total of four decks, two will be used for laboratories and two for operations and living quarters. Laboratory areas are designed for flexible, efficient changeover as research and experimental programs proceed. Provisions are included for such functions as data processing and evaluation, and test and calibration of optics. Zero gravity, which is desirable for the conduct of most experiments, will be the normal mode of operation, although the Integral Space Station may have an artificial-gravity capability.

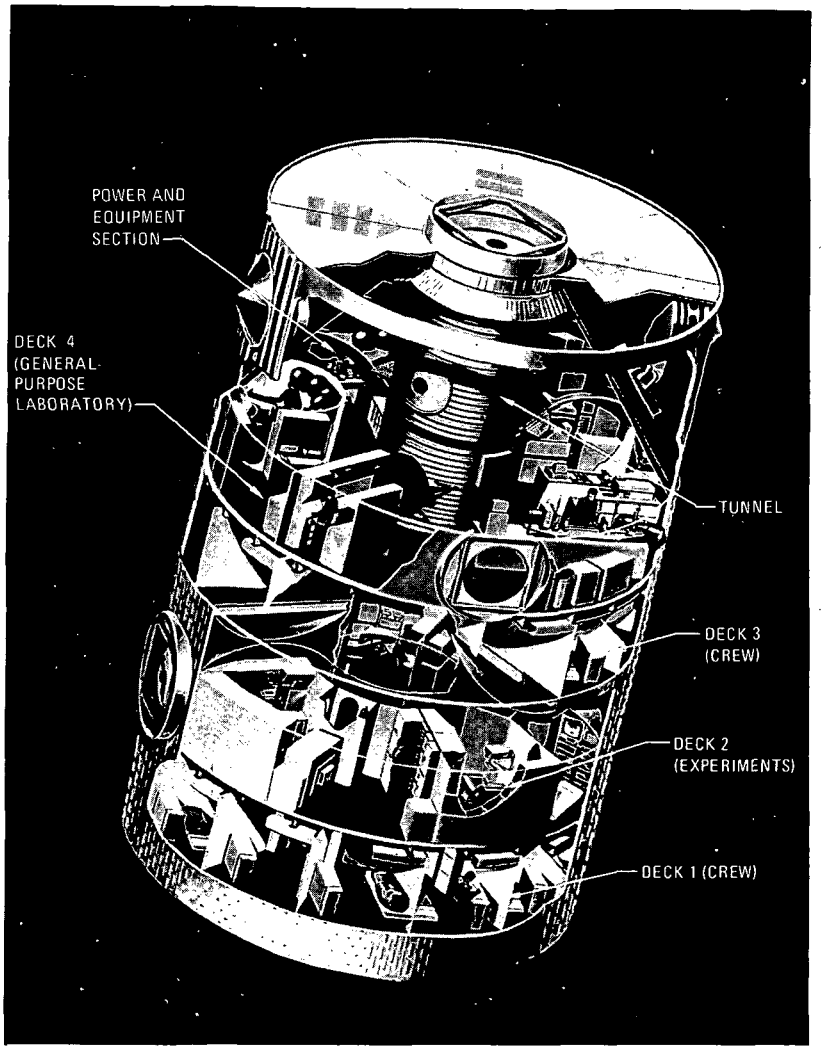


Figure 3-5. Core Module

The use of two separate pressurized modules or compartments with a common tunnel is compatible with the concept of long-term refuge and repair, rather than abandonment in the event of a major emergency. Essential life-support and control facilities are included in both compartments to permit continuation of the mission if one compartment has to be evacuated for any reason. The time and distance required for a crewman in any location to travel to a safe area are minimal because there are two escape routes from each compartment through the tunnel and through an airlock connecting the compartments. Each route terminates in a different place. Hatches are sized for free passage of pressure-suited crewmen.

There are seven docking ports, five on the cylindrical surface and one at either end of the Space Station. Figure 3-7 shows the locations of these ports and their utilization by attached modules, free-flying modules, and crew/cargo modules. Each port has a 1.5-meter (5-foot) diameter access door and an atmosphere seal between the Space Station and the docked module.

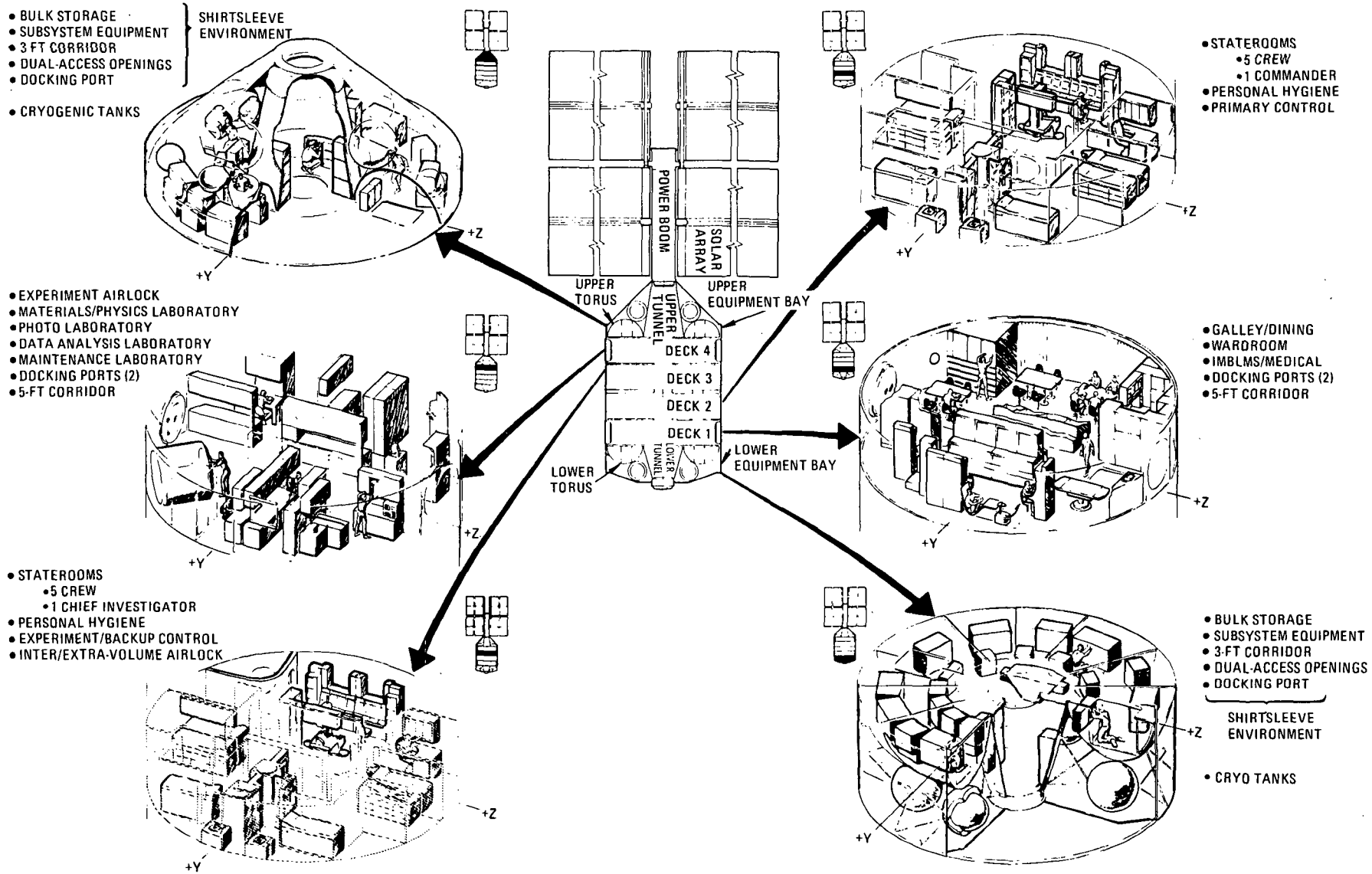


Figure 3-6. Solar-Powered Integral Space Station

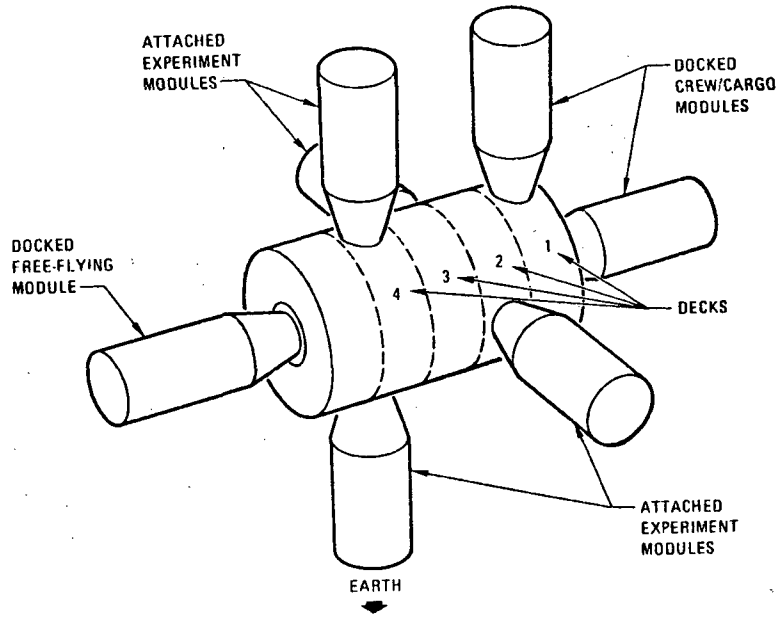


Figure 3-7. Docking Port Locations

In addition to the experiments carried out within the Space Station, others will be conducted in modules that will be either docked to the Space Station or free-flying. The Station will support the free-flying modules, which will periodically return to it for servicing and maintenance. One approach to the conceptual implementation of the investigations described in this document is shown in Figure 3-8. Studies on implementation are still being conducted and, with the additional and modified requirements developed in this updated Blue Book, the modes of accommodation may change significantly.

3.3.2 MODULAR SPACE STATION. Modular Space Station concept studies have recently been initiated by NASA. The objectives of these studies are to (1) develop concepts for a modular Space Station that can be assembled in Earth orbit with Space Shuttle payloads, and (2) exploit the potential advantage of flexibility of development or operation of the Space Station inherent in the modular build-up with Shuttle-launched payloads.

A Modular Space Station might take the form indicated in Figure 3-9.

Using the Shuttle to transport these elements to orbit, a Modular Space Station with capability equivalent to the large Integral Space Station could be built up over a period of time with approximately 17 launches. Inherent in this approach are scheduling advantages for payload development, integration and checkout, and for refurbishment and/or modification of a particular module by returning it to earth on a shuttle return flight.

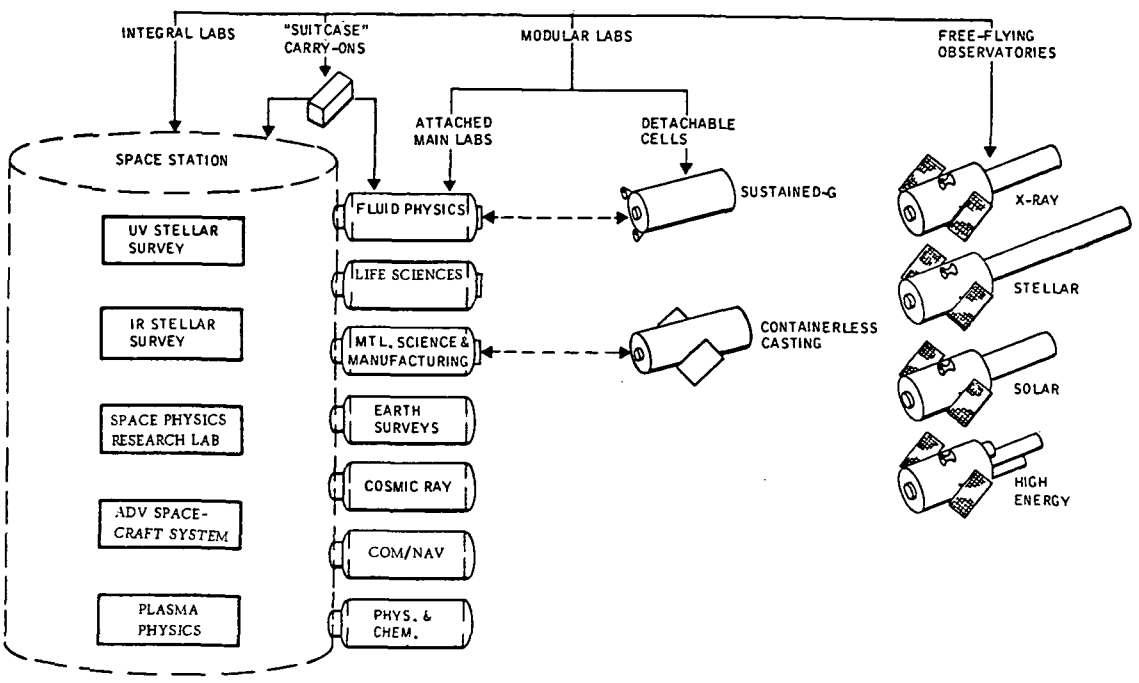


Figure 3-8. Space Station Research and Applications Capabilities

The interface problems with a modular station are not minor, however. To furnish the support requirements for each module will necessitate interface connections at each mating section for power, environmental control, data management, etc.

Nevertheless, the overall concept of a modular Space Station presents an interesting method of developing a total Space Station capability and at the same time having the capability to perform some of the earth orbital research programs.

Crew quarters, control centers, experimental facilities, etc., are housed in separate basic structural elements. The central assembly element provides interface connection and passageway between the basic structural elements. The manipulator element has externally mounted manipulating arms which may be used for taking the elements from the Shuttle and positioning them in place on the Modular Assembly.

The basic structural elements and the central assembly element are approximately 8.7 meters (29 feet) long and 4.2 meters (14 feet) in diameter. The airlock passageway clearance is 1.5 meters (5 feet) in diameter.

3.4 EXPERIMENT MODULES

Experiment modules containing laboratory facilities will operate either attached to a Space Station, attached to a Shuttle (Shuttle-sortie mode), or will be free-flying depending on experiment requirements such as pointing, stabilization, g level, etc.

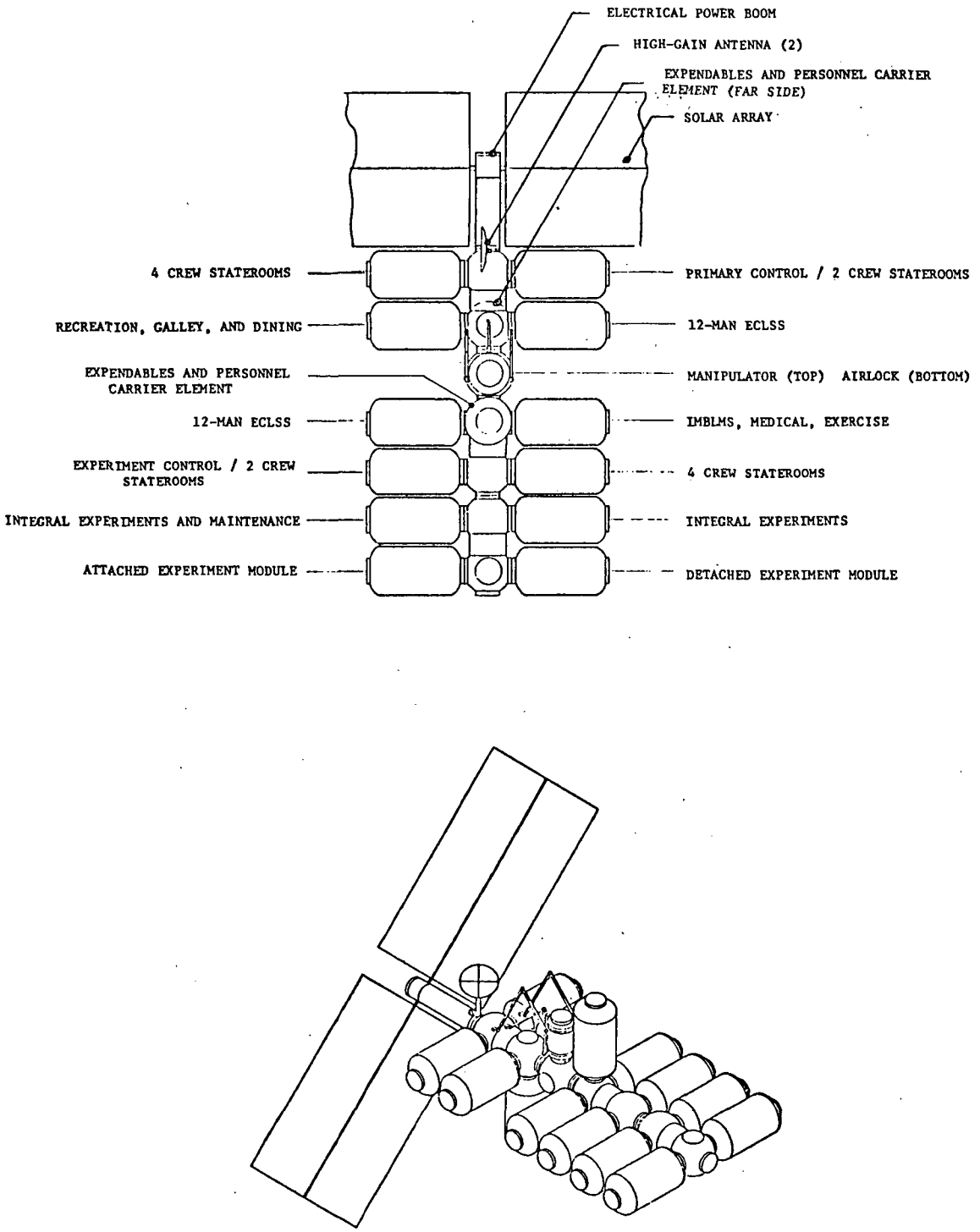


Figure 3-9. Twelve-Man Modular Space Station

These modules will be sized to fit into the payload bay of the Space Shuttle. The Shuttle-sortie mode is described in the following section. Experiment Modules, as they might be operated in conjunction with a Space Station, are discussed in this section.

In operation with the Space Station, experiment modules, which are attached, interface with and utilize the Space Station subsystems for primary power, etc. The free-flying modules have their own support subsystems but may utilize the data storage and transmission systems on the Space Station as well as the personnel for modification, maintenance, and repair. In the attached mode, scientists and technicians will live aboard the Space Station proper but may enter the modules while conducting their experiments. The experiment control areas in the attached modules will have a shirt-sleeve environment which will be supplied by the Space Station for long-duration operations. These modules will be sized to fit in the Shuttle payload bay.

Free-flying modules primarily support astronomical instruments that require a high degree of stability and pointing accuracy and must avoid the areas of contamination which may surround the Space Station.

An artist's concept of an attached module containing Earth Observations equipment is shown in Figure 3-10 and a free-flying module is shown in Figure 3-11.

3.5 SHUTTLE-SORTIE SUPPORT TO EXPERIMENT PROGRAMS

A possible mode for accommodating experiment programs prior to or in lieu of the operational availability of a space station exists with the concept of using the Earth-to-orbit Space Shuttle as a short term orbital base for conducting experiments. This concept evolves around the use of the Shuttle and minimum additional support equipment to carry aloft research equipment and, where appropriate, scientists and technicians, to conduct experiments during relatively short stay times in low Earth orbit. In cases where man is not directly required for experiment operation, such as most astronomy observations, the concept includes leaving the equipment in orbit to accomplish the program with periodic servicing by subsequent Shuttle flights.

The primary operating modes envisioned for Shuttle-sortie operations, depicted in Figure 3-12, are as follows:

a. Modes where man is directly involved in the conduct of the experiment program: In these cases the research equipment is carried aloft in the Shuttle along with the necessary support equipment such as crew quarters, life support and data management provisions. In the attached modes the experiment equipment and crew remain attached to the Shuttle and experiments are conducted during the Shuttle stay time on orbit of perhaps 5 to 30 days. The experiments would be conducted either extended from the Shuttle payload bay, as shown, or possibly from within the bay. The assembly is returned to Earth after completion of the 5- to 30-day experiment program.

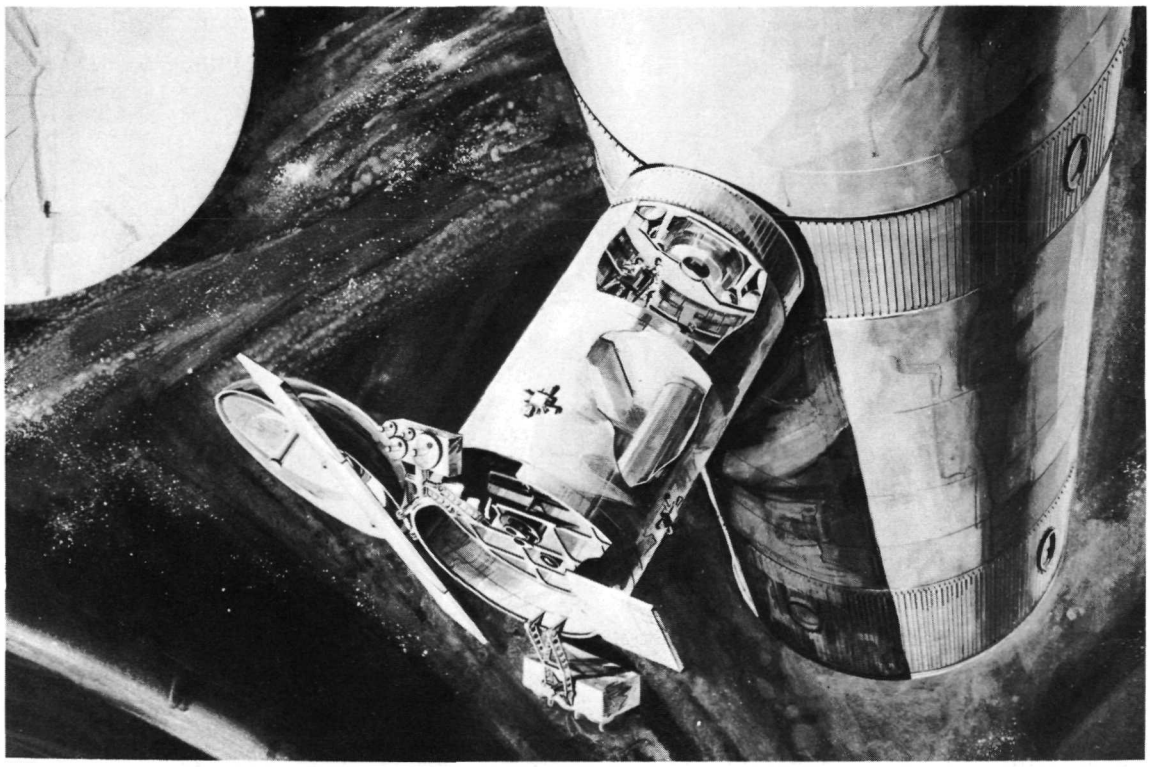


Figure 3-10. Attached Module

In the detached mode, the experiment equipment and crew are placed in orbit by the Shuttle and retrieved after 30 to 45 days by another Shuttle.

Two potential configurations for accommodating the crew and support equipment are shown in Figures 3-13 and 3-14. In Figure 3-13, a separate support module is attached to the experiment module. In Figure 3-14, the crew and support equipment are contained within the experiment module. Studies currently being conducted by NASA are evaluating these methods of implementation.

b. Modes where man is required only for periodic logistics, maintenance, update or retrieval of the experiment and is not directly involved in conducting the experiment program: In these cases the experiment equipment is carried aloft by the Shuttle, normally without an experiment crew, for unmanned automated experiment operations. Two basic operating modes are considered likely:

 1. The experiment equipment is placed in orbit from a Shuttle to commence experiment operations; the Shuttle returns to Earth and periodically visits the experiment equipment on subsequent flights for logistics and servicing. This mode is pictured in Figure 3-15, which shows the servicing operation with an astronomy module.

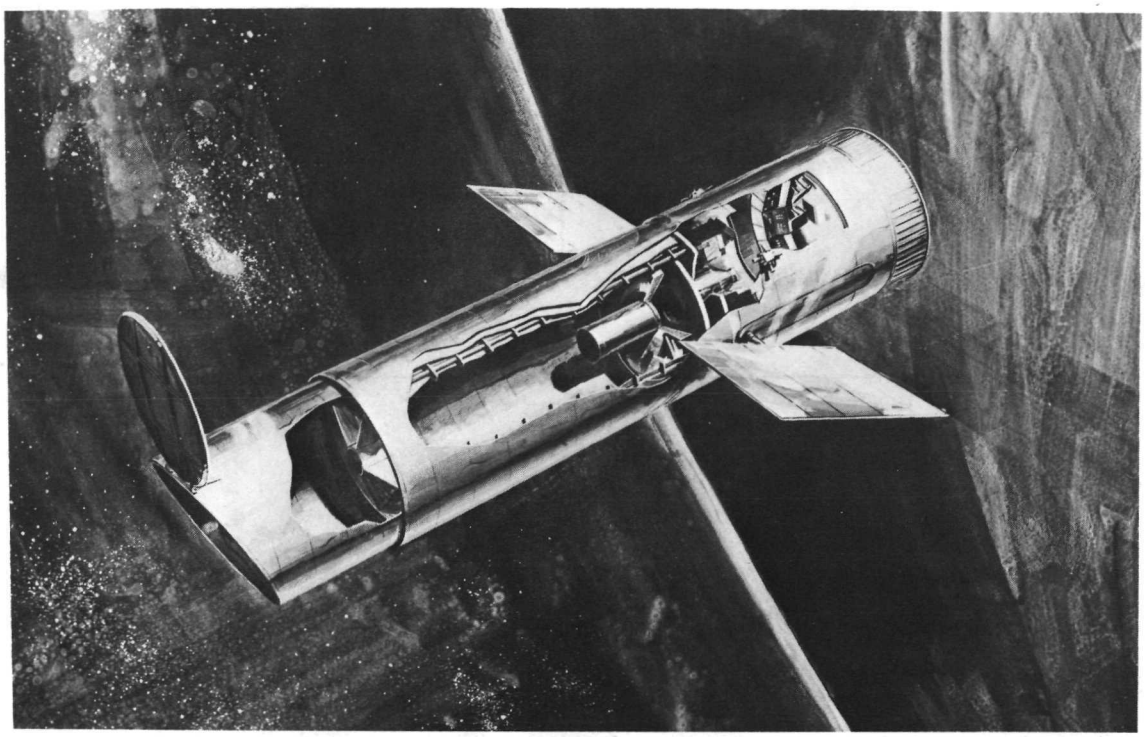


Figure 3-11. Free-Flying Module

2. The experiment equipment is self-contained and automated and needs only delivery to the proper orbit to accomplish the experiment program while remaining attached to the Shuttle, after which it is returned to the ground. This concept is depicted in Figure 3-16. All normal servicing of experiment equipment would be accomplished on the ground to avoid the EVA required in the unpressurizable payload bay.

It is likely that variations of the above basic modes will be developed to meet the needs of particular experiment programs. The concept includes consideration for operations at orbital altitudes and inclinations other than that of the Space Station orbit, which may be particularly beneficial to the experiment program, or where payload weights dictate use of a lower energy orbit.

Those experiment operations which can be conducted in the Shuttle-sortie mode will be affected by the characteristics and capabilities of the Space Shuttle system, particularly those of the Shuttle orbiter. A few examples of these characteristics which must be considered are listed below. In many of these cases, limitations of the orbiter capabilities can be overcome or supplemented by support equipment carried as payload, as depicted earlier.

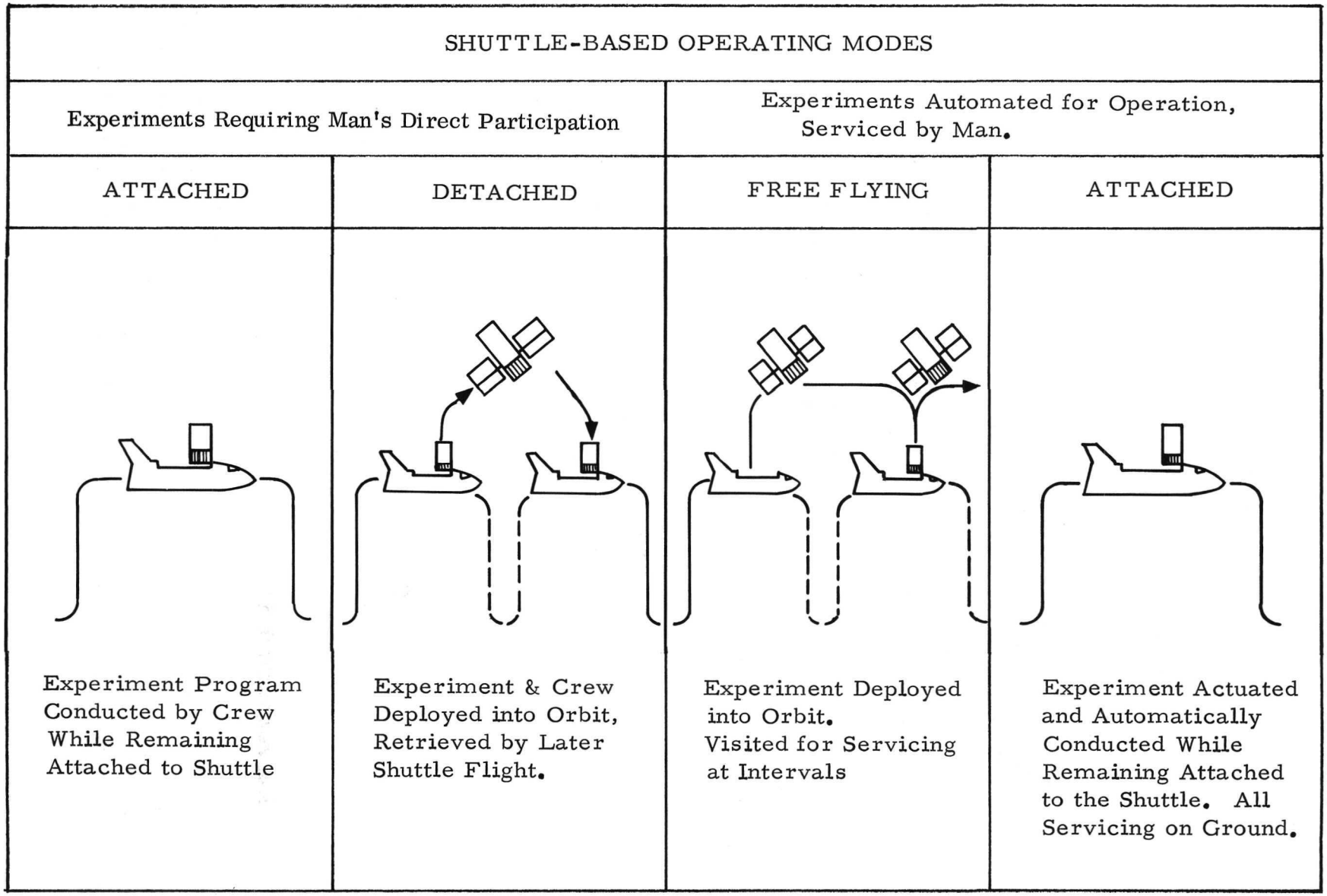


Figure 3-12. Shuttle-Based Experiment Operations

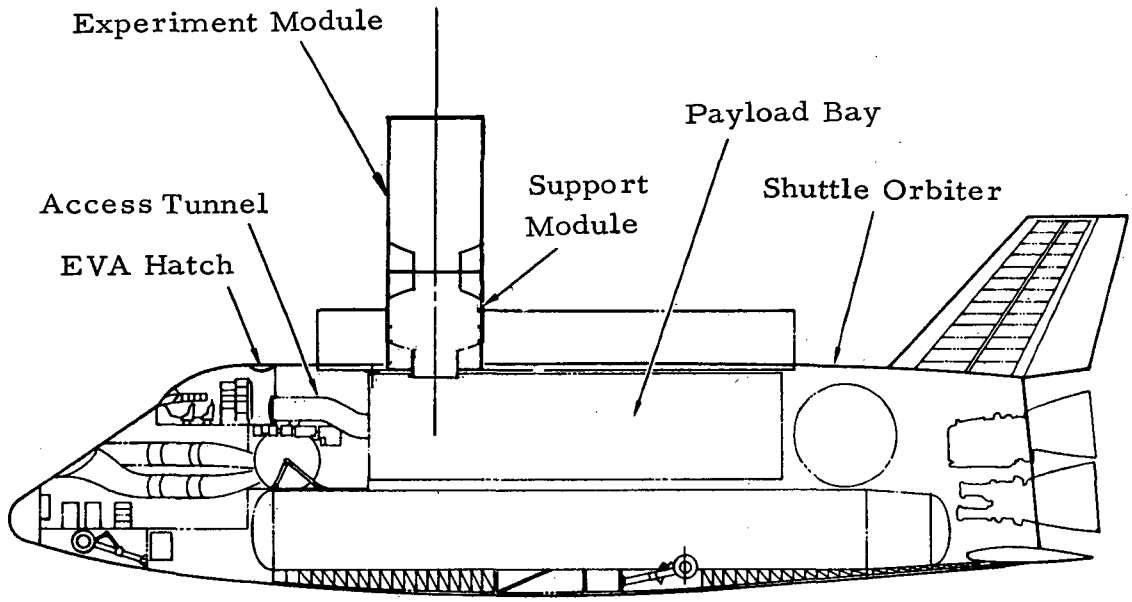


Figure 3-13. Man-Conducted Experiment Operations Using Separate Experiment and Support Modules

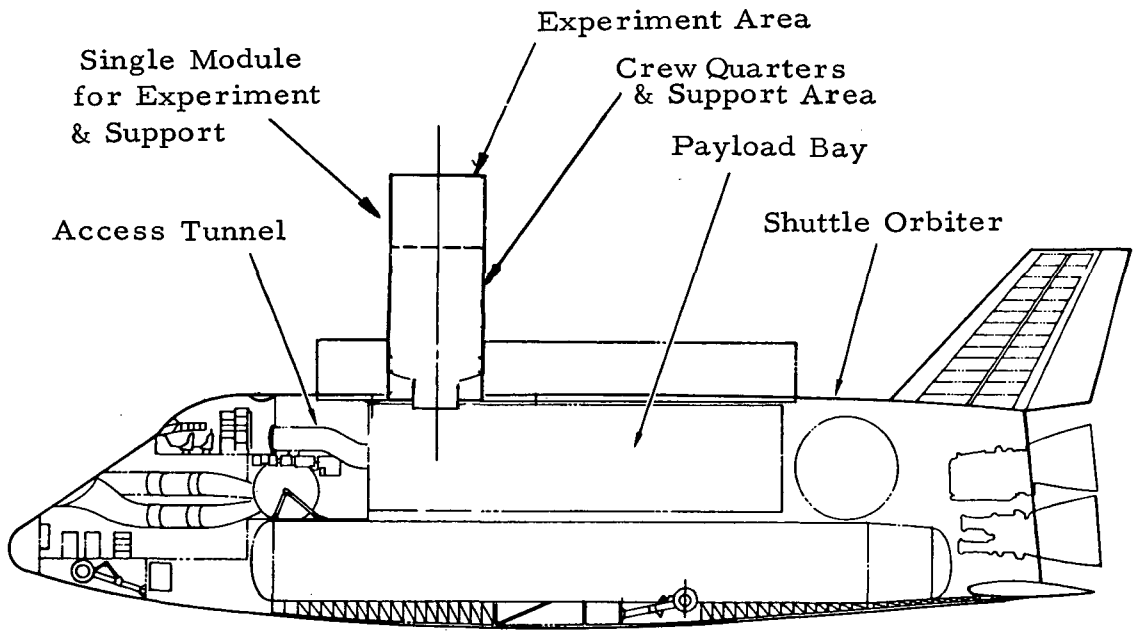


Figure 3-14. Man-Conducted Experiment Operations Using Single Module For Experiment and Support

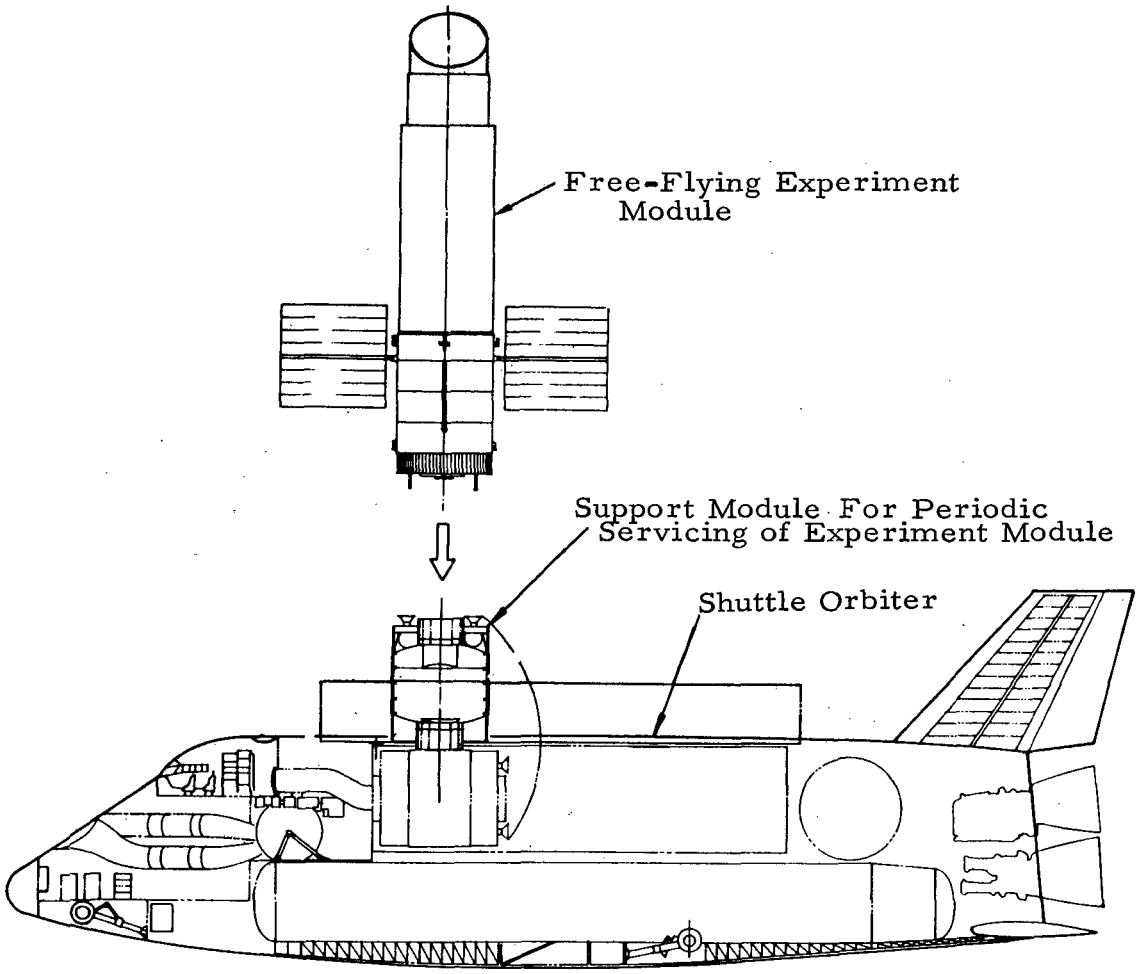


Figure 3-15. Free-Flying, Unmanned, Man-Serviced Experiment Operation

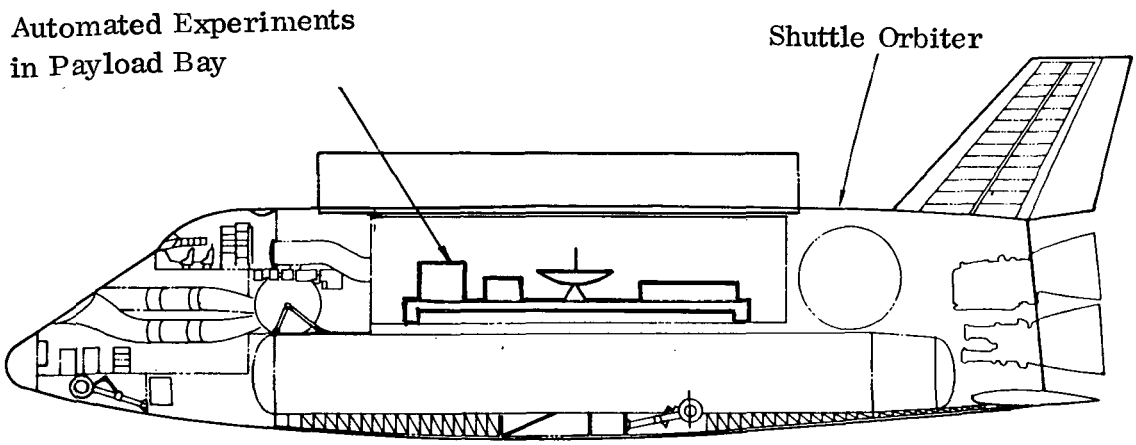


Figure 3-16. Attached Automated Experiment Operation

a. Shuttle pilots will have limited, if any, time to conduct or participate in experiment operations. Any significant degree of man participation will necessitate carrying an experiment crew as payload.

b. Shuttle systems will have limited, if any, capability to provide power, data, crew EC/LS or other support to experiment operations necessitating that these items also be provided by systems carried as part of the payload.

c. Nominal stay time on orbit is 5 days. However, it is likely that it will be possible to extend this to 30 days by carrying as payload all the required expendables and supplies.

d. The orbiter pointing accuracy and stability will fall short of the requirements of some experiments, and must be provided by the support equipment carried as payload.

VOLUME I

SECTION 4

FPE SUMMARY DATA AND DISCUSSION

SECTION 4

FPE SUMMARY DATA AND DISCUSSION

4.1 FPE SUMMARY DATA

The summary data contained in this section is derived from the data presented in Volumes II through VIII. The data on Table 4-1 summarizes the requirements for each FPE except for Fluid Management and EVA which can not be summarized at the FPE level on any rational basis due to either the complex and diverse nature of the facility requirements or the uniqueness of each experiment set-up or operation. Experiments Requirements Summary data is presented in Table 4-3 for Fluid Management and in Table 4-4 for EVA.

The summary data presented in Table 4-1 represents, in the best judgement of NASA scientists, the overall facility and experiment requirements to accomplish a realistic experimental program. The rationale for selection of the summary parameters is in some instances arbitrary but has as a basis the total NASA experience and knowledge of prior flight and experiment definition and integration programs.

In Table 4-1, the parameters are defined as follows:

a. Mass - The total mass of the equipment, instrumentation, test specimens, experiment control consoles, supplies, expendables, etc., in a research facility required to support an FPE.

b. Volume - The volume of the equipment defined in the mass above.

c. Power - The maximum average power requirement of such duration as to necessitate consideration in design of the size of the power supply.

d. Crew Skills - The crew skills are listed by code number as presented in Table 4-2.

e. Data Rate - Average data collection rate for an experiment or a group of experiments within the research facility including housekeeping data requirements.

f & g. Logistics, Up and Down - The thirty-day average of equipments, supplies, expendables, etc., which are to be transported by the Shuttle to and from the research facility.

h. Pointing and Stability - The requirement for pointing is given in terms of accuracy required in pointing at a particular target. The stability represents the maximum allowable excursion or allowable excursion rate, depending on the particular case, about the nominal pointing axis.

Table 4-1. FPE Requirements Summary

	FPE	MASS (WEIGHT) kg (lb)	VOLUME m^3 (ft^3)	POWER kW	CREW SKILLS	DATA RATE kbs	LOGISTICS 30-DAY AVG kg/(lb) UP	LOGISTICS 30-DAY AVG kg/(lb) DOWN	POINTING ACCURACY	STABILITY	ALTITUDE & INCLINATION DESIRED	ALTITUDE & INCLINATION ACCEPTABLE	UNIQUE ENVIRONMENTAL REQUIREMENTS	REMARKS
ASTRONOMY	X-Ray	4240 (9350)	72 (2540)	0.53	5	10^4	800(1) (1800)	800(1) (1800)	5×10^{-6} rad (1 arcsec)	5×10^{-6} rad (1 arcsec)/ Obser. Time	740 km (400 n.mi.) 0°	370 km (200 n.mi.) > 0°	Minimum contamination	(1) Exchange sensors once each year (2) Cryogenics 500 kg/ 6 mo. (3) Film/30 da
	Stellar	5390 (13,200)	75 (2620)	0.86	5,6	10^5	320(1) (705) 220(3) (484)	320(1) (705) 220(3) (484)	Desired: 5×10^{-6} rad (1 arcsec) Acceptable: 5×10^{-5} rad (10 arcsec)	2.4×10^{-8} rad (0.005 arcsec)/Obser. Time	460 km (250 n.mi.) 50°	460 km (250 n.mi.) > 0°	Minimum contamination Minimum vibration	
	Solar	3470 (7340)	71.5 (2500)	0.97	5	10^6	450(1) (996) 100(3) (230)	450(1) (996) 100(3) (230)	Desired: 5×10^{-7} rad (0.1 arcsec) Acceptable: 1.2×10^{-5} rad (2.5 arcsec)	5×10^{-8} rad (0.01 arcsec)/Obser. Time	370 km (200 n.mi.) Sun-synchronous	370 km (200 n.mi.) 0-55°	Minimum contamination	
	Intermediate Size U.V. Telescope	1680 (3370)	11.5 (395)	0.63	5,6	10^4	345(1) (760)	345(1) (760)	Vehicle: 8.7×10^{-3} rad (30 arcmin) Telescope: 2.4×10^{-5} rad (5 arcsec)	Vehicle: 2.4×10^{-5} rad (5 arcsec)/ Obser. Time Telescope: 2.4×10^{-6} rad (0.5 arcsec)/ Obser. Time	460 km (250 n.mi.) 55°	370 km (200 n.mi.) > 0°	Minimum contamination	
	High Energy Stellar	3400 (7510)	24 (845)	0.49	5,6,14	10^4	290(1) (643)	290(1) (643)	5×10^{-6} rad (1 arcsec)	5×10^{-6} rad (1 arcsec)/ Observ. Time	740 km (400 n.mi.) 0°	370 km (200 n.mi.) > 0°	Avoid high flux & energy Van Allen belts	
	I.R.	1500 (3300)	74 (2614)	0.3	5	10^4	1100(1)(2) (2420)	200(1)(2) (440)	5×10^{-6} rad (1 arcsec)	5×10^{-6} rad (1 arcsec)/ Obser. Time	500 km (270 n.mi.) 60°	460 km (250 n.mi.) 25 to 55°	Minimum contamination. Minimum heat load orbit.	
PHYSICS	Space Physics Research Lab	2648 (5800)	3.6 (127)	1.0	5,6,12	6.3×10^3	132 (280)	132 (280)	8 mrad (0.5°)	0.16 mrad/sec (0.01°/sec)	> 185 km (100 n.mi.) Polar	> 50°	Minimum contamination	(4) Not including sub-satellites (5) Not including TAD 4350 kg (9588 lb) (6) Magnet/Dewar once/year
	Plasma	550(4) (1210)	1.4(4) (50)	0.3	6,12	3.1×10^3	11 (24)	11 (24)	±8 mrad (±0.5°)	0.4 mrad/min (0.025°/min)	>185 km (100 n.mi.) Polar	> 50°	Minimum contamination	
	Cosmic Ray	15,700(5) (34,500)	137 (5720)	0.71	7,12	15×10^3	157 (345) 1360(5) (3000)	157 (345) 910(5) (2000)	±16 mrad ±1.0°	NA	185 km (100 n.mi.) 28°	520 km (270 n.mi.) 55°	Low background radiation	
	Physics & Chemistry	2700 (6200)	10 (350)	9.6	6,9,12,25	2.4×10^3	85 (200)	85 (200)	±0.05 rad (±3°)	NA	>185 km (100 n.mi.) Any	NA	Low g level (10^{-3} g max.)	
EARTH OBS	Earth Observations Facility	3490 (7720)	26 (930)	4.5	16,18,21, 22,19,26, 28	5 x 10^4	550 (1222)	550 (1222)	±8 mrad (±0.5°)	0.8 mrad/sec (0.05°/sec)	>185 km (100 n.mi.) Polar	> 50°	Minimum contamination	
COM NAV	COM/NAV Research Lab	756 (1670)	5.2 (184)	2.64	10,12,14, 17	1.04×10^3	28.6 (63)	28.6 (63)	0.175 mrad (0.01°)	1.75 mrad/sec (0.1°/sec)	> 185 km (100 n.mi.) > 0.49 rad	NA	NA	
MS/MS	Materials Science Research Lab	Minimum 215 (4750) Desirable 3700 (8300)	Minimum 22.3 (788) Desirable 38.2 (1350)	5.0	1,3,6,8, 10,12,14, 15,23,24, 25	10^3	Minimum 75 (165) Desirable 274 (605)	Minimum 75 (165) Desirable 274 (605)	NA	NA	NA	NA	Minimum 0 ± 10^{-3} g Desirable 0 ± 10^{-5} g	

Table 4-1. FPE Requirements Summary (Contd)

	FPE	MASS (WEIGHT) kg (lb)	VOLUME m^3 (ft^3)	POWER kW	CREW SKILLS	DATA RATE kbs	LOGISTICS 30-DAY AVG kg/(lb) UP	LOGISTICS 30-DAY AVG kg/(lb) DOWN	POINTING ACCURACY	STABILITY	ALTITUDE & INCLINATION DESIRED	ALTITUDE & INCLINATION ACCEPTABLE	UNIQUE ENVIRONMENTAL REQUIREMENTS	REMARKS
TECHNOLOGY	Contamination Measurements	190 (420)	0.68 (24)	0.7	6,12	107 +10 MHz T.V.	15 (33)	11 (25)	$\pm 8.7 \times 10^{-3}$ rad ($\pm 0.5°$)	NA	> 280 km (150 n.mi.)	Any S/C Operational Altitude	Experiment peculiar	
	Fluid Management	(SEE TABLE 4-3)												
	EVA	(SEE TABLE 4-4)												
	Advanced S/C Systems Test	670 (1500)	1.3 (46)	2.8	8,9,10, 11,12	18	70 (160)	70 (160)	48 nrad (0.01 arcsec)	NA	NA	NA	Experiment peculiar	
	Teleoperations	670 (1500)	4.4 (155)	0.3	10,11,12	4.9 +8.4 MHz T.V.	80 (180)	5 (11)	NA	NA	NA	NA	No parent S/C maneuvering during docking and undocking.	
LIFE SCIENCES	Medical Research	3010 (6675)	44 (1560)	3.55	1,2,3,4, 12,13,22	0.93	40 (90)	30 (68) 1st 2 yrs 36 (81) 3rd yr & on	NA	NA	NA	NA	No maneuvering during experiments	
	Vertebrate Research	1063 (2345)	38 (1340)	4.07	1,2,3,4 12,22	1.095	262 (578)	196 (433) 1st 2 yrs 236 (520) 3rd yr & on	NA	NA	NA	NA	Isolation from noise, vibration, & possibly EMI & ESI. Acceleration $<10^{-3}$ g.	
	Plant Research	2232 (4920)	16 (565)	3.42	1,3,12,22	0.74	67 (148)	50 (110) 1st 2 yrs 60 (132) 3rd yr & on	NA	NA	NA	NA	Isolation from noise, vibration, & possibly EMI & ESI. Acceleration $<10^{-5}$ g.	
	Microbiology Research	2081 (4600)	14.3 (515)	3.31	1,2,3,12	0.35	27 (60)	20 (44) 1st 2 yrs 24 (53) 3rd yr & on	NA	NA	NA	NA	Isolation from noise, vibration, & possibly EMI & ESI. Acceleration $<10^{-5}$ g.	
	Invertebrate Research	2044 (4520)	14 (495)	3.28	1,3,12	0.28	22 (49)	17 (38) 1st 2 yrs 20 (44) 3rd yr & on	NA	NA	Highest Inclination Possible	NA	Isolation from noise, vibration, & possibly EMI & ESI. Acceleration $<10^{-3}$ g.	
	LSPS	3339 (7360)	25 (883)	3.66	2,11,12, 22	330	101 (223)	76 (168) 1st 2 yrs 91 (201) 3rd yr & on	NA	NA	NA	NA	NA	
	MSI	2663 (5900)	31.4 (1110)	3.71	11,12,13, 21	7	136 (300)	102 (225) 1st 2 yrs 122 (269) 3rd yr & on	NA	NA	NA	NA	Controlled illumination & noise levels. Seclusion from visual & auditory distractions.	

Table 4-2. Crew Skills

1.	Biological Technician	14.	Optical Technician
2.	Microbiological Technician	15.	Optical Scientist
3.	Biochemist	16.	Meteorologist
4.	Physiologist	17.	Microwave Specialist
5.	Astronomer/Astrophysicist	18.	Oceanographer
6.	Physicist	19.	Physical Geologist
7.	Nuclear Physicist	20.	Photo Geologist
8.	Photo Technician/Cartographer	21.	Behavioral Scientist
9.	Thermodynamicist	22.	Chemical Technician
10.	Electronic Engineer	23.	Metallurgist
11.	Mechanical Engineer	24.	Material Scientist
12.	Electromechanical Technician	25.	Physical Chemist
13.	Medical Doctor	26.	Agronomist
		27.	Geographer

i. Orbital Altitude and Inclination - The desired and acceptable orbital altitude and inclination are presented.

j. Unique Environmental Requirements - The requirements are specific where required by the experiments or where an unusual ambient environment would result in degradation of the experiments.

Table 4-3. Fluid Management Experiment Requirements Summary

EXPERIMENT	MASS (WEIGHT) kg	(lb)	VOLUME m^3	(ft^3)	ENVELOPE m	(ft)	POWER REQUIREMENTS watts	CREW SKILLS	ENVIRONMENT REQUIREMENTS	EXPERIMENT TIME LIMITS hours		DATA REQUIREMENTS
2.4.1 Interface Stability												
Fluid	204	(450)	1.4	(50)	1.5 x 1.5 x 0.6	(5 x 5 x 2)	Nominal 100 Peak 500 for 10 sec	Electromechanical Technician 43 hr Thermodynamicist 10 hr	Controlled g level	Set-up	48.0 hr	Data generation rate = 760 bits/sec. Total data sampled = 7×10^6 bits; film storage = 1200 m (4000 ft), 4.5 kg (10 lb) TV = 5.8 MHz
Tanks	136	(300)								10^{-3} g	9.1	
Structural	68	(150)								10^{-4} g	9.1	
Instr.	16	(35)								10^{-5} g	9.1	
	424	935)										
2.4.2 Boiling Heat Transfer												
Tankage	27	(60)	1.5	(54)	0.9 x 0.9 x 1.8	(3 x 3 x 6)	Nominal 27 Peak 500 for 1 hr	Electromechanical Technician 12 hr Thermodynamicist 100 hr	Pressure 1.3×10^{-4} N/m^2 ($<10^{-6}$ Torr). Controlled g level	Set-up	12.0 hr	Data generation rate = 192 bits/sec. Total data sampled = 2×10^6 bits; film storage = 1900 m (6400 ft), 7.2 kg (16 lb) TV = 5.8 MHz
Structure	27	(60)								10^{-3} g	10.4	
Propellant	77	(170)								10^{-4} g	17.8	
Trans Sys	55	(120)								10^{-5} g	70.3	
Vent Sys	45	(100)										
Press.	18	(40)										
Instr	22	(50)										
	270	(600)										
2.4.3 Capillary Studies												
Chambers	101	(230)	1.8	(65)	0.9 x 0.9 x 0.9	(3 x 3 x 3)	Nominal 115 Peak 165 for 4 min	Thermodynamicist 18 hours	Temperature Nominally 294° K (70° F). Controlled g level	10^{-3} g	6.0 hr	Data generation rate = 25 bits/sec. Total data sampled = 1.62×10^6; film storage = 0
Tanks	89	(195)								10^{-4} g	6.0	
Fluids Methanol	254	(560)								10^{-5} g	6.0	
Ethanol	86	(190)										
Pentane	408	(900)										
Support Sys	13	(160)										
	1011	(2235)										
2.4.4 Condensing Heat Transfer												
Cond Pkg	44	(97)	2.1	(75)	1.8 x 1.5 x 0.75	(6 x 5 x 2.5)	Nominal 1.21 kW Peak 1.65 kW for 12 sec 25 times	Electromechanical Technicion 1 hr Thermodynamicist 3.35 hr	Controlled level	Set-up	1 hr	Data generation rate = 5780 bits/sec. Total data sampled = 17×10^6; film storage = 1860 m (6000 ft), 6.8 kg (15 lb)
Suppt Eqpt	17.7	(39)								10^{-3} g	126 min	
Fluids	2	(5)								10^{-4} g	75 min	
Cameras	52	(115)										
Heat Sink	27	(60)										
Power Supply	30	(65)										
Instr	9	(20)										
Controls	16	(35)										
Misc	18	(40)										
	216	(476)										
2.4.5 Two-Phase Flow Regimes												
Structure	45	(100)	0.34	(12)	0.6 x 0.6 x 0.9	(2 x 2 x 3)	Nominal 167 Peak 300 for 15 sec	Electromechanical Technician 16 hr Thermodynamicist 12 hr	Constant thermal environment 294° K ~(70° F). Controlled g level	Set-up	16.0 hr	Data generation rate = 160 bits/sec. Total data sampled = 1×10^5 bits; film storage = 1300 m (4400 ft), 5 kg (11 lb)
Fluid	164	(360)								10^{-3} g	6.0	
	209	(460)								10^{-5} g	6.0	

Table 4-3. Fluid Management Experiment Requirements Summary (Contd)

EXPERIMENT	MASS (WEIGHT) kg (lb)	VOLUME m^3 (ft^3)	ENVELOPE m (ft)	POWER REQUIREMENTS watts	CREW SKILLS	ENVIRONMENT REQUIREMENTS	EXPERIMENT TIME LIMITS hours	DATA REQUIREMENTS
2.4.6 Propellant Transfer Tanks & Stor LH_2 GH_e Fill & Vent Sys Instr Insul Test Eq TV Press	227 (500) 386 (850) 9 (20) 114 (250) 23 (50) 18 (40) 41 (90) 41 (90) 41 (90) 896 (1980)	51 (1800)	2.4 x 3.6 x 5.4 (8 x 12 x 18)	Nominal 1.3 kW Peak 4 kW for 6 hr	Electromechanical Technician 8 hr Thermodynamicist 24 hr	Pressure 1.3×10^{-4} N/m^2 ($<10^{-6}$ Torr). Controlled g level	Set-up 80 hrs 10^{-3} g 7.0 10^{-4} g 1.0 10^{-5} g 7.0 Coast 33.0	Data generation rate = 160 bits/sec. Total data sampled = 8×10^6 bits; film storage = 0
2.4.7 Long Term Storage of Cryogenics Tank Shroud LH_2 Fill & Vent Sys Instr Insul TV Zero-G Vent Reliquefier	451 (1000) 373 (800) 1134 (2500) 113 (250) 91 (200) 127 (280) 14 (30) 19 (42) 68 (150) 2393 (5250)	59 (2095)	3.2 x 3.2 x 5.7 (10.5 x 10.5 x 19)	Nominal 150 Peak 1055 for 7.25 hr	Electromechanical Technician 24 hr Thermodynamicist 400 hr	Pressure 1.3×10^{-4} N/m^2 ($<10^{-6}$ Torr). Controlled g level	Set-up 24.0 hrs 10^{-3} g 12.0 10^{-4} g 199.0 10^{-5} g 125.0 Coast 4100.0	Data generation rate = 160 bits/sec. Total data sampled = 5×10^7 bits; film storage = 0
2.4.8 Slush Propellant Tanks & Ins Heaters Structure Press. Sys Test Eq Slush Fill & Vent Sys Instr	236 (520) 11 (25) 54 (120) 41 (90) 54 (120) 80 (175) 113 (250) 68 (150) 657 (1430)	24 (840)	2.1 x 3.6 x 3 (7 x 12 x 10)	Nominal 40 Peak 1200 for 2 min	Electromechanical Technicial 8 hr Thermodynamicist 60 hr	Pressure 1.3×10^{-4} N/m^2 ($<10^{-6}$ Torr). Controlled g level	Set-up 8.0 hr 10^{-3} g 3.6 10^{-4} g 42.0 10^{-5} g 152.0	Data generation rate = 160 bits/sec. Total data sampled = 5×10^6 bits; film storage = 0
2.4.9 Two-Phase Dynamics Test Sec Support Inst	9 (20) 66 (145) 20 (45) 95 (210)	0.8 (10)	0.6 x 0.6 x 0.75 (2 x 2 x 2.5)	Nominal 400 Peak 1000 for 1.8 sec	Electromechanical Technician 2 hr	Controlled g levels	Set-up 2.0 hr 10^{-3} g 0.7 10^{-5} g 0.7 Coast 0.7	Data generation rate = 1.6 bits/sec. Total data sampled = 650 bits; film storage = 7.5 m (25 ft)
2.4.10 Channel Flow Systems Test Sec Support Inst	23 (50) 91 (200) 34 (75) 148 (325)	0.59 (21)	0.6 x 0.8 x 1.2 (2 x 2.7 x 4)	Nominal 750 Peak 1800 for 1.8 sec	Electromechanical Technician 8 hr	Controlled g levels	Set-up 8 hr 10^{-3} g 2 10^{-5} g 2 Coast 2	Data generation rate = 10.0 bits/sec. Total data sampled = 3000 bits; film storage = 12 m (40 ft)

Table 4-3. Fluid Management Experiment Requirements Summary (Contd)

EXPERIMENT	MASS (WEIGHT) kg (lb)	VOLUME m^3 (ft^3)	ENVELOPE m (ft)	POWER REQUIREMENTS watts	CREW SKILLS	ENVIRONMENT REQUIREMENTS	EXPERIMENT TIME LIMITS hours	DATA REQUIREMENTS
2.4.11 Conical Flow Systems Test Sec Support Systems	9 (20) 34 (75) 20 (45) 63 (140)	0.62 (22)	0.6 x 0.9 x 1.1 (2 x 3 x 3.5)	Nominal 200 Peak 750 for 1.5 sec	Electromechanical Technician 2 hr	Controlled g levels	Set-up 2.0 hr 10^{-3} g 0.5 10^{-5} g 0.5 Coast 0.5	Data generation rate = 0.1 bits/sec. Total data sampled = 100 bits; Total film storage - 6 m (20 ft)

Table 4-4. EVA Experiment Requirements Summary

	WEIGHT kg (lb)	VOLUME m^3 (ft^3)	ENVELOPE m (ft)	POWER	CREW SKILLS	ENVIRONMENT REQUIREMENT	EXPERIMENT TIME LIMITS	DATA REQUIREMENTS	RANGE m (ft)	COMMUNICATION	RADAR	STABILIZATION AND CONTROL	THERMAL CONTROL
4.1 ASTRONAUT MANEUVERING UNIT	2 Units 120 (265)	6(20)	3 x .6 x 1.5 (9 x 2 x 5)	Standby = 193 W Average = 332 W Maximum = 370 W	Elect/ Mech Tech	100% O_2 @ 26 kN/m^2 (3.75 psia) to Pressure Suit	8 Hr Maximum	5000 Bits/sec	90 (200) Any Orbital Direction	Voice	None	N/A	Stored ~ 220 to 340 K (-60 to 160F) Operational 270 to 320K (20 to 120 F)
4.2 MANEUVERABLE WORK PLATFORM	2 Units 1448 (3200)	5(200)	3 x 3 x 4 (10 x 9 x 14)	2 KW-Hr Per Mission with Redundancy (14 Hour Turn Around)	Elect/ Mech Tech	100% O_2 @ 26 kN/m^2 (3.75 psia) to Pressure Suit Metabolic Rate Avg = 370 Watt (1250 BTU/Hr Peak = 630 Watt (2150 BTU/Hr	8 Hrs plus 2 Hr Rescue	8000 Bits/sec	2000(4400) Any Orbital Direction	Range = 3 KM Voice Telemetry Alert Alarm	Range = 10.5 KM Accuracy = ± 0.3% to 2 KM	N/A	Man and Onboard Subsystems

4.2 ASTRONOMY

4.2.1 X-RAY STELLAR ASTRONOMY. The X-ray stellar astronomy experiment objectives are: 1) identification and location of soft X-ray sources in the 12.4 to 0.12 keV (1 to 100 angstrom spectral range) 2) determination of the physical mechanisms responsible for X-ray emissions; 3) determination of the amount and distribution of the energy associated with such sources; 4) determination of angular size of X-ray sources.

The X-ray astronomy facility shown in Figure 4-1 consists of six independent X-ray collection and direction sensing assemblies: 1) a high-resolution (1,000 cm^2) X-ray telescope, 2) a large-area moderate resolution X-ray telescope, 3) a proportional counter array, (4) a scintillation counter assembly, (5) a crystal spectrograph, and 6) a transient X-ray phenomena detector. Although the assemblies are independent of each other, correlation of the data when all six are operated simultaneously yields data over an energy spectrum from about 0.1 keV to 12 keV and provides a basis for analysis of interfering signals.

The experiments employ aspect sensing for image stabilization and optical cross correlations. The high-resolution X-ray telescope is used for high-resolution imaging to 5×10^{-6} radians (one arc second) and spectrometry to 10^{-11} m (0.1 Å). The large-area (5,000 cm^2) X-ray telescope is used for maximum sensitivity detection, imaging, spectrometry, and polarimetry. A large-area proportional counter is used for cross calibration of energy levels and measurement of flux and intensity variations. Scintillation counting extends the correlation to higher energy levels. A higher energy

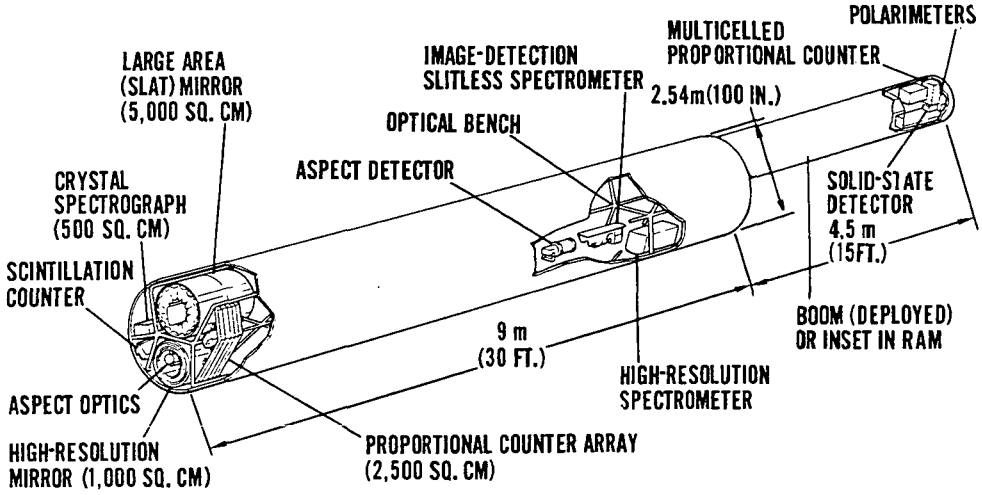


Figure 4-1. X-Ray Stellar Astronomy Facility

large-area crystal spectrometer enables detection of spectral lines, enabling calculation of source temperatures and velocities (doppler shifts). Early detection of transient extra solar X-ray emissions is accomplished by a 2π steradian coverage transient X-ray detection array. The transient detection array provides direction information for pointing the other five collector/instrument assemblies. Requirements data for this FPE are presented in Table 4-1

4.2.2 ADVANCED STELLAR ASTRONOMY. Advanced stellar astronomy objectives include improved observation of stellar objects, acquisition of technology development information, and development of a basis for a National Astronomy Space Observatory.

Technology experiments include tests of alternative techniques for alignment, calibration, guide star acquisition, stellar object location, and stabilization. Furthermore, evaluation-type experiments will be performed for in-space optics tolerance control, image motion compensation, pointing reference angle accuracy, and thermal effects.

Stellar observations experiments will include alignment, acquisition and object location tasks, as well as high-resolution registration of objects by electronic or backup film imaging units. Each stellar source brightness will be measured by spectrophotometry and its spectrum analyzed by low- and high-resolution spectrometry. Optional polarimetry will be accomplished.

A conceptual arrangement of the experiment equipment is shown in Figure 4-2.

This facility is capable of accommodating an electronic imaging camera, backup film camera, a spectrophotometer, a Rowland Circle UV spectrometer, a modified echelle spectrometer, and a Fourier spectrometer. Additional instruments can be substituted

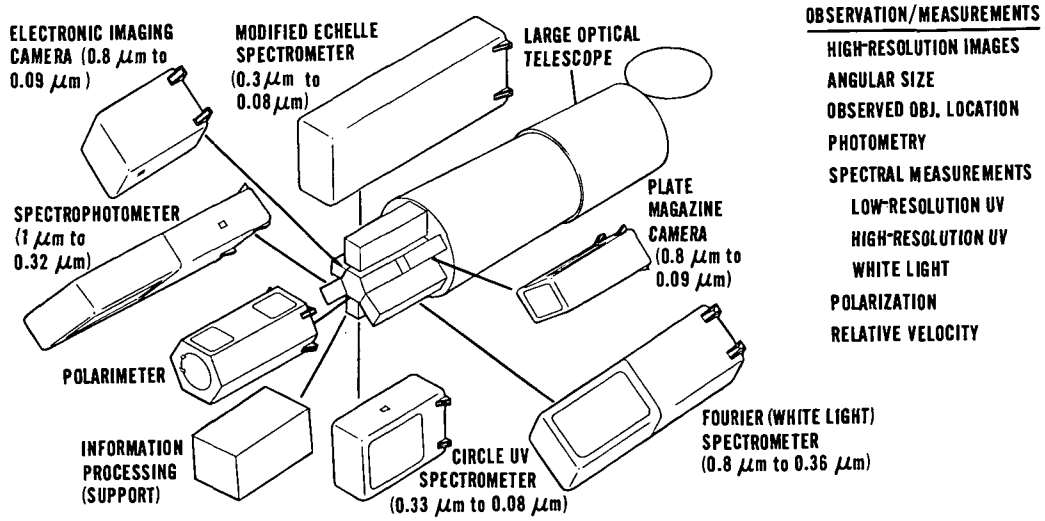
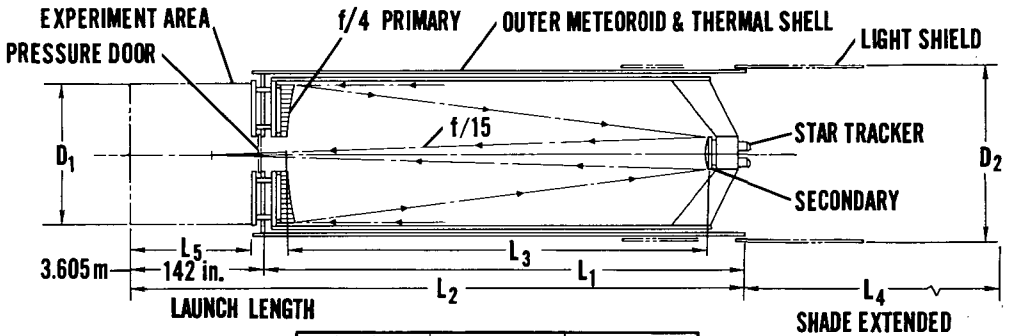


Figure 4-2. Stellar Observation Experiments

for any of the initial set of instruments to accommodate new experiments. Cooperative information management is desired to optimize experiment control and output data quality.

The telescope in this facility may be either two or three meters in diameter at the aperture as shown in Figure 4-3. These configurations will allow for attachment or retrofit of various instruments at one of the foci or beam switched optical points to enable accommodation of instruments for a number of investigators. The telescopes will be capable of being monitored and remotely controlled from the ground as well as from a nearby space station or a logistics (shuttle) service vehicle. Summary requirements data is presented in Table 4-1.



TELESCOPE	2m (80 in.)		3.05m (120in.)	
DIMENSION	m	in.	m	in.
D_1	3.05	120	3.82	150
D_2	3.25	128	4.27	168
L_1	6.92	272	10.21	402
L_2	10.50	414	13.80	544
L_3	5.78	227	9.01	354
L_4	2.54	100	3.87	152
L_5	3.05	120	3.05	120

Figure 4-3. Advanced Stellar Astronomy Facility

4.2.3 ADVANCED SOLAR ASTRONOMY. The following solar astronomy objectives are to be supported: 1) greater continuity of solar observations is needed to obtain a more complete time history than now available, 3) correlated visible, magnetograph, UV, X-UV, and X-ray observations of best spatial and spectral resolution to enable studies of solar granular structure and incipient flare activity. Detailed image, velocity, flux, magnetic-field contours, and spectral information are needed. Coronal activity also needs to be monitored concurrently with observations of selected locations on the sun, 3) information is needed for man-optimization of solar observation activities in space, and 4) techniques will be developed for a long lifetime solar information acquisition facility.

The spectral range covered is from 1.1×10^{-6}m to 2×10^{-10}m (11,000 Å to 2 Å).

The experiments employ in-space alignment, calibration, solar observation area location, and electronic imaging techniques, enabling multispectral observation, spectrometry, and magnetic field measurements to be made. Concurrent visible UV, X-UV, and X-ray imaging and spectrometry provide information on solar characteristics that enables future prediction of solar flares and a better understanding of solar processes. Magnetic field and coronal observations contribute to the total solar analysis versus time.

The advanced solar astronomical facilities shown in Figure 4-4 are expected to consist of two groups of telescopes and associated instruments. One group is intended to be used to examine phenomena in solar granular structure and areas of high activity with best available spectral and spatial resolution, and the second group measures phenomena in the region of the solar corona. Summary requirements data is presented in Table 4-1.

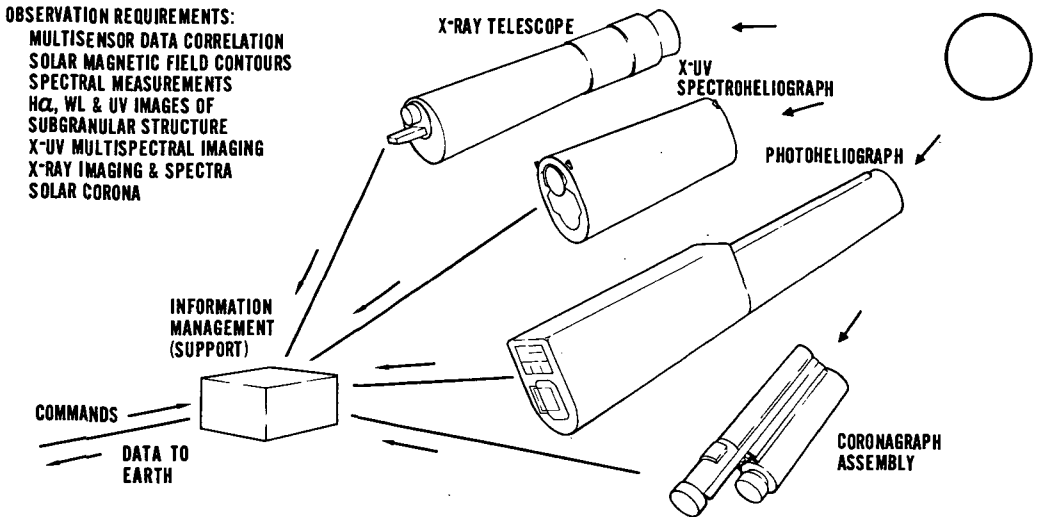


Figure 4-4. Advanced Solar Experiment Facilities

4.2.4 INTERMEDIATE-SIZE UV TELESCOPES. A more thorough wide-field survey, together with objective grating spectrometry, will be conducted for mapping and UV luminosity distribution studies of the celestial sphere. The narrow-field detailed survey will provide specific spectral images of galactic emissions, star clusters, nearby galaxies, and planetary nebulae. Monochromatic ultraviolet images obtainable by slitless spectrography provide estimates of distributions of dust-free pure-emission gas clouds. Specific UV spectrometry will be performed on selected stars, brighter quasars, and novae. The spectral range to be covered will be from 0.4 μm to 0.013 μm (4,000 A to 130 Å).

The ultraviolet facility items consist of a narrow-field, 0.94 meter (37 inch) Ritchey-Chretien Cassegrain type of telescope shown in Figure 4-5 and a wide-field 0.3 meter diameter telescope shown in Figure 4-6.

The 0.94 meter narrow-field telescope assembly consists of the telescope, three-axis gimbals, an elevator/retractor mechanism, and a hangar chamber (for servicing).

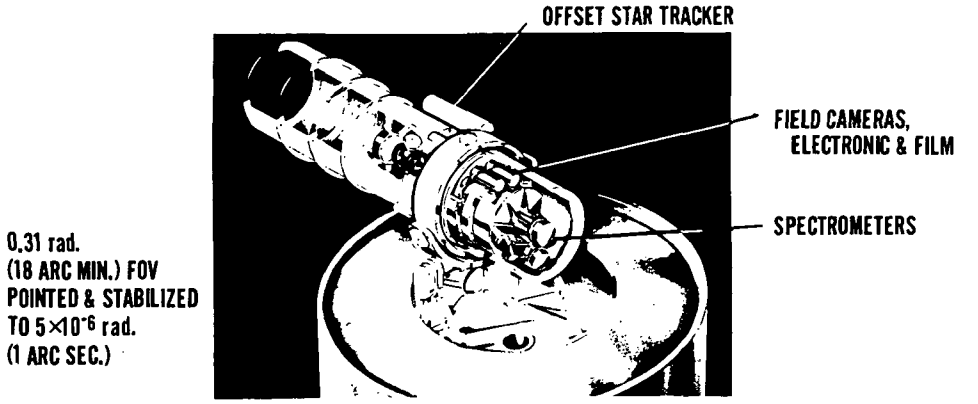


Figure 4-5. Narrow-Field UV Telescope 0.94m, All Reflective

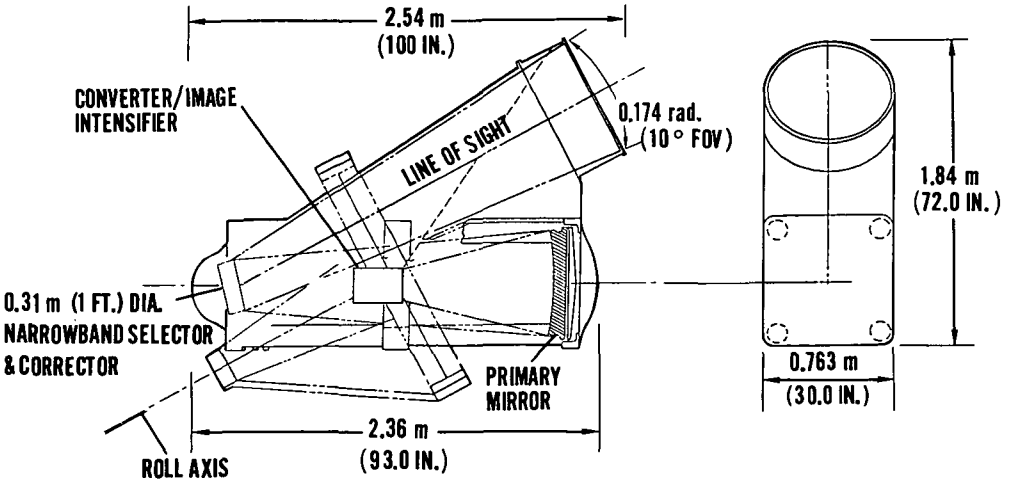


Figure 4-6. Wide-Field UV Telescope

The wide-field UV telescope has a 0.174 radian (10°) field of view and accommodates electronic/backup film imaging and objective grating spectrographic accessories and instruments.

4.2.5 HIGH-ENERGY STELLAR ASTRONOMY. The objectives of high-energy stellar astronomy are to extend knowledge of astronomical phenomena by measurements of flux, direction, spectral distribution, and polarization simultaneously for each source investigated. Also, the angular dimensions, intensity, and location of selected X-ray and gamma ray sources are to be measured. The spectrum shape information will enable determination of characteristics of emission mechanisms. Equipment and operational techniques also need evaluation for use in space to enable continuing improvement. The energy range covered is from 0.1 keV to 30 GeV.

The experiment/observation processes will include alignment, calibration, aspect sensing, and location, as well as flux, direction, and spectral measurements of the radiation from each source. The 0.1 to 5 keV range will be measured with the aid of an X-ray telescope, and the 1 to 20 keV spectral range by means of a venetian-blind telescope and spectrometer. Nine narrow-band asymmetric crystal cone assemblies will be used to detect and measure spectral lines in the 6 to 10 keV range. A large-area X-ray counter-array will be used to measure flux and map distributions spatially within the 0.1 to 100 keV spectral range. Low background detection and spectrometry will be accomplished in the 6 to 400 keV range. A Ge(Li) detector in the 0.6 to 10 MeV range will measure gamma ray flux, spectra, and variations. A high-energy gamma ray spectrometer will measure flux, source direction, and spectral distribution in the 10 to 30 GeV range.

The high-energy stellar astronomy facilities, illustrated in Figure 4-7, will consist of seven kinds of energy collectors and associated instruments, enabling correlated measurements of direction, flux, and energy distribution (spectral) characteristics of radiation from any selected stellar source from 0.1 keV to 30 geV. The facility items are: 1) 100 cm^2 X-ray telescope (0.1 to 5 keV), 2) venetian-blind X-ray telescope (1 to 20 keV), 3) nine asymmetric crystal cone spectrometer-polarimeter assemblies (6 to 10 keV), 4) large-area X-ray counter-array (0.1 to 100 keV), 5) low background detector array (0.6 to 400 keV), 6) gamma ray spectrometer (0.06 to 10 MeV), and 7) large-area spark chamber (10 MeV to 30 geV).

4.2.6 IR ASTRONOMY. The IR stellar survey objectives include: 1) distribution and locations of IR sources, 2) luminosities (brightness) of IR sources, 3) correlatable characteristics of IR spectrums to be compared with X-ray spectra, 4) information about cool stars, protostars, galactic objects, the galactic center, extra-galactic sources, Seyfort galaxies, and quasistellar objects.

The experiment/observation processes include: in-space alignment, calibration, acquisition, and source location, as well as experiment detector array scanning, radiometry, and high-resolution spectrometry. Spectral coverage is from 1,000 μm to 1 μm.

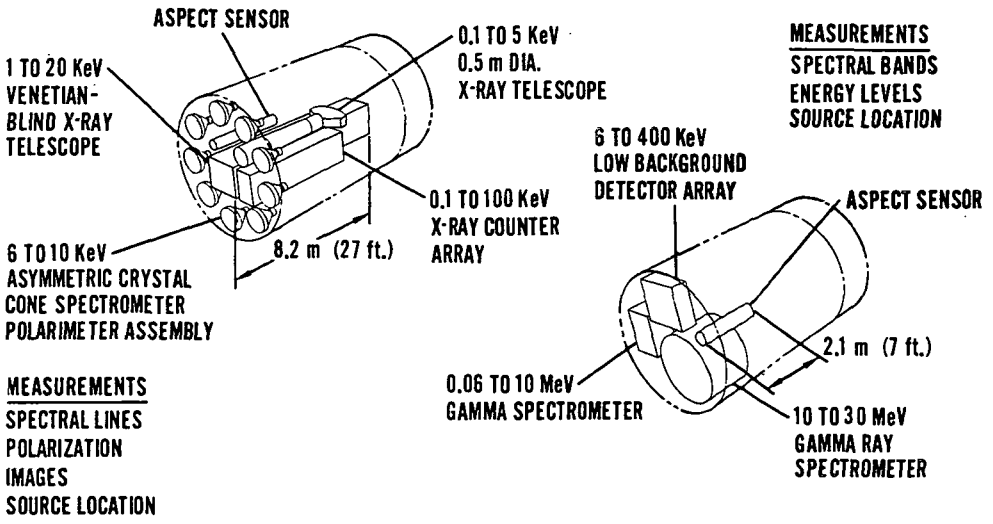


Figure 4-7. High-Energy Stellar Astronomy Facilities

The IR survey facility, shown in Figure 4-8, consists of a one-meter IR telescope cooled to 27° K, mounted on a two-axis set of gimbals, with access through an airlock extendable through the azimuth bearing when the telescope is docked. The telescope accommodates a linear detector array, and a Michelson interferometer cooled to 2° K within the experiment chamber compartment behind the cooled Cassegrain mirror. The telescope also includes a regulated supply to flow liquid neon through the heat exchanger manifolding on the inside of the telescope superinsulation. A similar supply is used for superfluid helium to the detector units. An aspect sensor operating in the visible spectrum is used to point the telescope and provide location references during scanning and spectrometry.

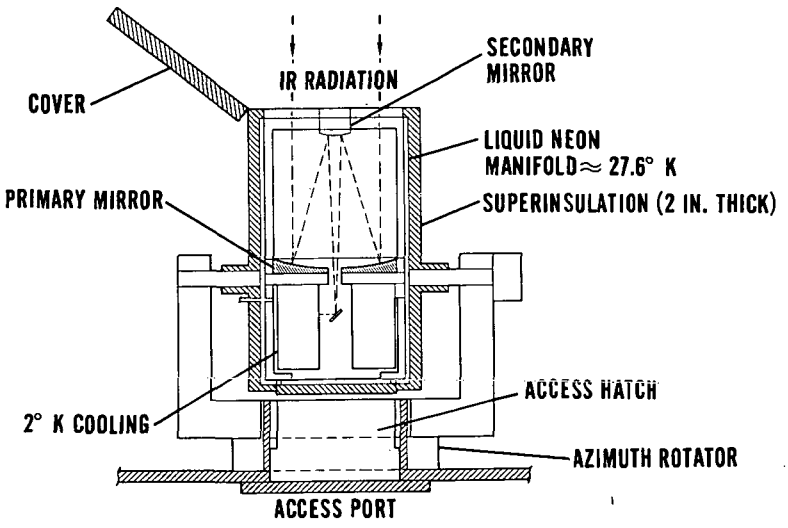


Figure 4-8. IR Astronomy Facility (One-Meter Telescope)

4.3 PHYSICS

4.3.1 SPACE PHYSICS RESEARCH LABORATORY. Four scientific categories of experiments will be conducted in the facilities of the Space Physics Research Laboratory.

The scientific objective of the first category of experiments, Atmospheric and Magnetospheric Science (including Aurora), is to investigate the chemical and energy conversion processes which control the structure of the thermosphere as well as the dynamics of the magnetosphere. This will be accomplished through a family of measurements and observations, many of them simultaneous, of the ambient environment, incident energetic particles and radiations, as well as auroral and airglow emissions.

Exemplary of the Cometary Physics experiments is the gaseous release of NH_3 and ICN, which has as its objective the evaluation of the plausibility of photolysis as the causative mechanism of cometary spectra.

Experiments in Meteoroid Science are intended to provide information on the trajectories of meteoroids, as well as their mass, velocity, and composition. The five experiments being considered are typical of these categories: 1) recovery, 2) compositional analysis 3) small meteoroid mass/velocity measurements, 4) optical detection of mass and velocity of larger meteoroids, and 5) penetration.

The small telescopes and spectroscopes of this facility will also be used to supplement observations by larger facilities. Among these will be spectroscopic observations in the UV spectral regions.

Twenty-five scientific instruments will be installed in this laboratory.

Three airlocks are recommended, each capable of mounting two selectable instruments on gimbals on extendable rails. This provides a basic capability for use of six instruments simultaneously with independent pointing capability. The optical instruments and particle sensors will be the prime users of the airlocks. The components of this facility are illustrated in Figure 4-9.

The ambient environment sensors, gaseous release devices, and meteoroid sensors will be mounted externally on the spacecraft surface or on booms. Within the spacecraft, provisions will be made for experiment control and monitoring, maintenance and calibration, as well as sensor storage. Data processing is expected to be provided by a separate central facility. Summary data is presented in Table 4-1.

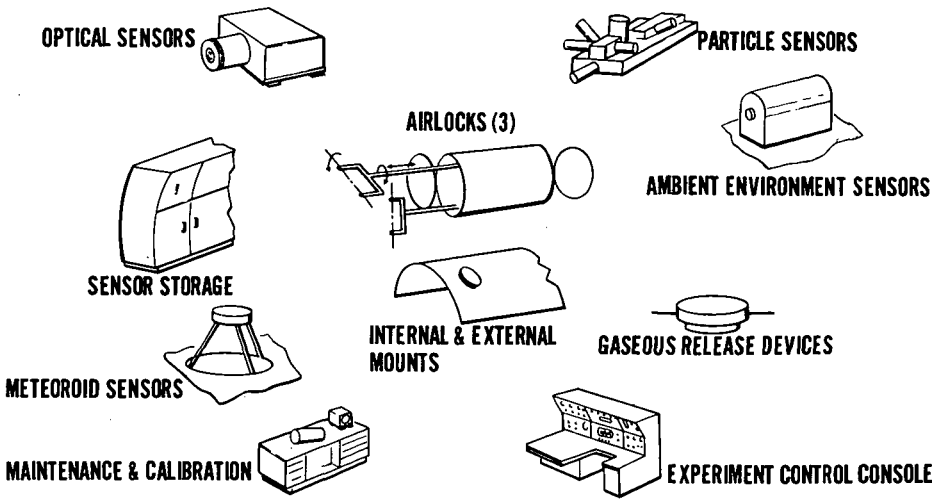


Figure 4-9. Space Physics Research Laboratory (Typical Equipment)

4.3.2 PLASMA PHYSICS AND ENVIRONMENTAL PERTURBATION LABORATORY. The prime objective of this FPE is to establish an orbital laboratory for the performance of a variety of plasma physics experiments. Four experiment groups are representative of this area:

Plasma Wake around orbital bodies

Plasma Resonances and their Harmonics

Wake Particle interactions with VLF

Electron and Ion Beam Propagation

The major elements of this laboratory, as indicated in Figure 4-10, include a family of surface and boom-mounted instruments, as well as an airlock for deployment of subsatellites and the TV and particle accelerators. Subsatellites will be stored on board and utilized as depcited. The upper left sketch indicates the boom and surface-mounted instruments probing the near wake of the spacecraft, with a subsatellite probing the far wake. The right sketch indicates the antennas of the plasma resonance experiment, as well as a cooperative subsatellite. The bottom figure illustrates VLF and particle beam measurements along a magnetic field line with the cooperation of a conjugate subsatellite. The summary data requirements are given in Table 4-1.

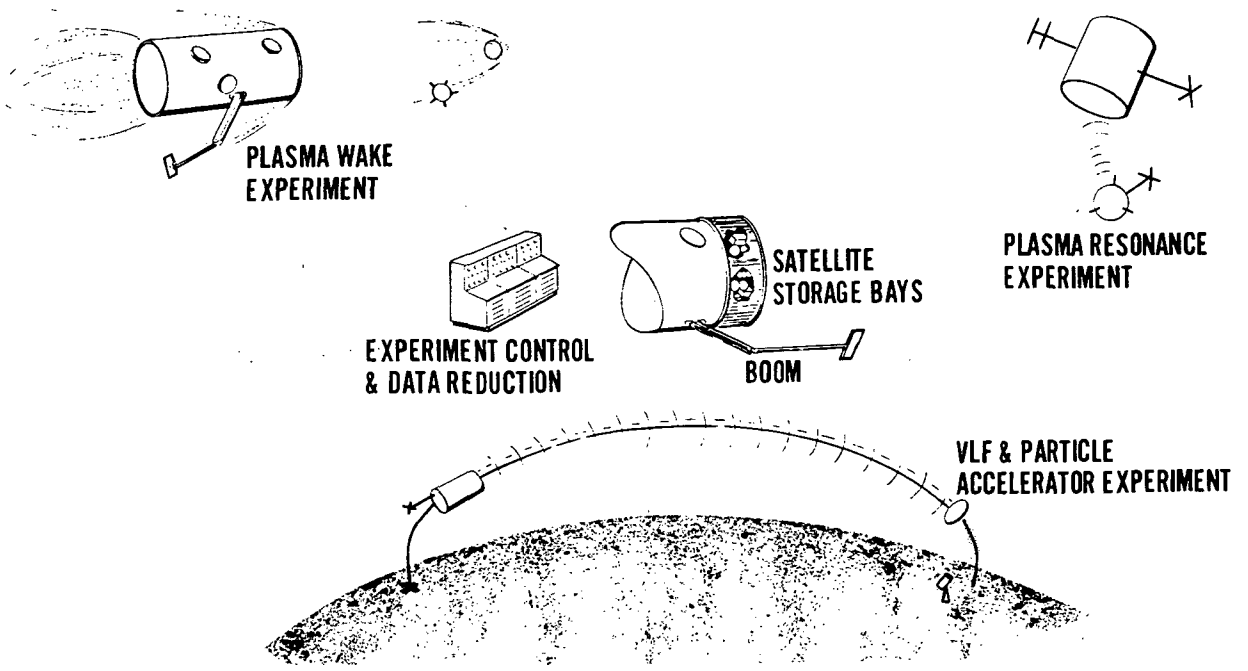


Figure 4-10. Plasma Physics and Environmental Perturbation Laboratory (Experimental Elements)

4.3.3 COSMIC RAY PHYSICS LABORATORY. The basic objectives for the Cosmic Ray Physics Laboratory are:

a. To advance understanding of astrophysical phenomena through accurate measurement of:

 1. Flux and energy spectra of cosmis ray nuclei ($>10^{10}$ eV)
 2. Charge composition of cosmic ray nuclei ($1 \leq Z \lesssim 130$)
 3. Electron-positron energy spectra ($> 10^{10}$ eV)
 4. Isotopic composition of light nuclei

b. To search for:

 1. Theoretically predicted elementary particles (e.g., quarks, magnetic monopoles)
 2. Antimatter stars

As the program evolves and as experimental results become available, the emphasis will be placed on those experiments which reflect the current scientific interest at that time. Among the potential future goals are 1) measurement of the production cross sections for the spallation products of heavy nuclei of hydrogen, and 2) measurement of the cross sections and other properties of strong nuclear interactions at high energies commensurate with current scientific interest and availability of artificial accelerators. In addition, the laboratory will continually be updated by including newly developed instrumentation as it becomes available.

The illustration in Figure 4-11 indicates how the instrumentation will be arranged in a 15-foot-diameter cylindrical module. The upper view shows the three experiment channels, I, II, and III, and their associated detector bays. The lower view illustrates the optional feature of entire dewar-magnet assembly removal and replacement. It is anticipated that this operation would be required at yearly intervals for such a passive cryogenic system and may be preferable to transferring liquid helium at zero-g. Summary requirements data for this FPE is presented in Table 4-1.

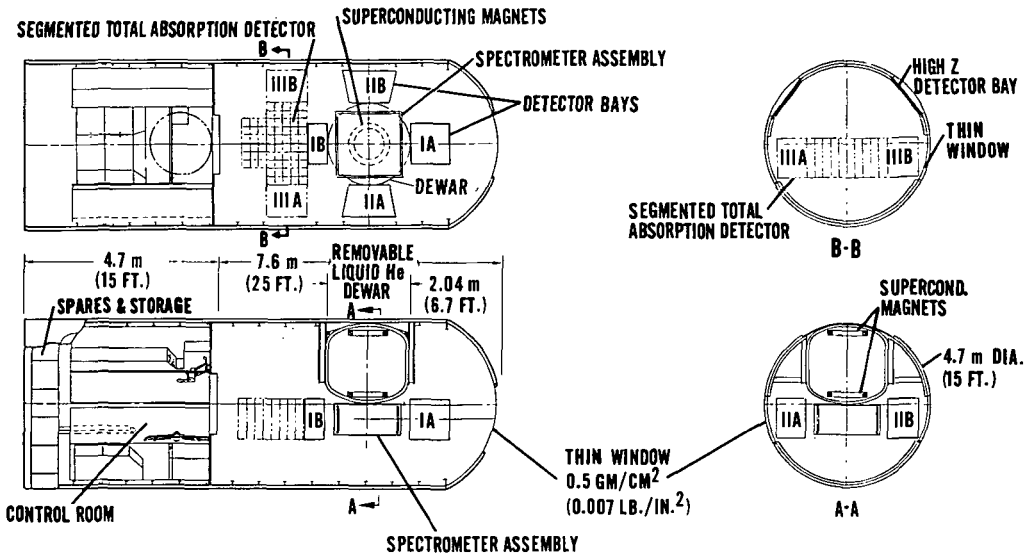


Figure 4-11. Cosmic Ray Physics Laboratory (Equipment)

4.3.4 PHYSICS AND CHEMISTRY LABORATORY. This FPE describes typical experiments which will be conducted using a space laboratory for performing physics and chemistry experiments that make optimum use of the unique environmental conditions available: 1) zero gravity enables processes to be studied without convective flows attributable to density gradients, 2) access to the external space environment permits performing experiments under high vacuum conditions with no wall effects, 3) solar electromagnetic radiation provides a natural ionizing and excitation source for studying chemical phenomena, and 4) the intense hypervelocity atomic, molecular and ion beam generated by a spacecraft moving at orbital velocity through the upper atmosphere makes possible the study of particle and gas-surface interactions in the free molecular flow regime.

The laboratory will have work stations that receive experiments packaged in standardized configurations as carry-on "suitcase" payloads for plug-in to the work stations.

The laboratory will contain the necessary power, gases, vacuum lines, and airlocks, as well as multipurpose test equipment and instrumentation. A central experiment control and data collection system will also be provided.

Basic laboratory equipment as shown in Figure 4-12 is fundamental to the laboratory and has a major impact on the design of the laboratory structure and subsystems; e.g., some items require hull penetrations, clear working areas, high power, and cooling. Support equipment is general purpose equipment which is relatively small, has low mass, and has limited resource demands. A summary of the requirements for this FPE is presented in Table 4-1.

| | BASIC LAB EQUIPMENT | | | | | | | | | | | | | | SUPPORT EQUIPMENT | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LABORATORY EQUIPMENT / TYPICAL EXPERIMENTS | AIRLOCKS (2): 1 m (3 FT.) DIA. | FEEDTHROUGHS: ELECT., FLUID, MECH. | VIEW PORTS: VISIBLE, IR, UV | BENCH AREA, EXP. SETUP: 3 m^3 (106 $FT.^3$) | BENCH AREA, g ISOLATION ($10^{-4}g^1$) | VACUUM LINES | FIRE & EMERG. SYSTEM | WASTE DISPOSAL SYSTEM | ENVIRONMENTAL CHAMBER | HIGH VACUUM CHAMBER | SUPERCONDUCTING MAGNET | GLOVE BOXES: VACUUM, CLEAN, HAZARDOUS | CRYOGENIC SUPPLIES: N_2 & He | EXTENDABLE BOOM: 12m (40 FT.) | DATA ACQUISITION SYSTEM | CAMERAS: CINE, STILL, TV | GAS SUPPLIES | SPECTROPHOTOMETER | MAGNETIC FIELD METER | ELECTRIC FIELD METER | DATA DISPLAYS | OSCILLOSCOPE | VOLTMETERS, AMMETERS, ETC. | FREQUENCY METER | REFERENCE JUNCTION | OPTICAL CALORIMETER | OPTICAL PYROMETER | GAS CHROMATOGRAPH | EMISSION SPECTROMETER | PRESSURE & VACUUM SENSORS | TEMPERATURE SENSORS | DISPLACEMENT & VELOCITY SENSORS | ACCELERATION SENSORS | SPECIAL-PURPOSE POWER SUPPLIES | NUCLEAR PARTICLE DETECTORS | POLARIMETER | ELECTRON SPIN RESONANCE SPECTROMETER |
| CRITICAL POINT PHENOMENA | | | | ● | ● | | | | | | | ● | | | ● | ● | | | | | ● | | | | | | | | ● | ● | | | | | | | |
| GAS/SURFACE INTERACTION | ● | ● | ● | ● | | | | | | | | ● | | ● | ● | | | | | | ● | ● | ● | ● | | | | | | | ● | ● | ● | | | | |
| MOLECULAR BEAM SCATTERING | ● | ● | ● | ● | | | | | | | | ● | | ● | ● | | ● | | | | ● | ● | ● | ● | | | | | | | | ● | ● | ● | | | | |
| HEAT TRANSFER | | | | ● | ● | | | ● | | ● | | | | | ● | ● | ● | | | | ● | | ● | | ● | | | | ● | ● | | ● | ● | | | | |
| CHEMICAL LASER | ● | ● | ● | ● | | | | ● | | | | | | ● | ● | | ● | ● | | ● | ● | | ● | | ● | ● | | | ● | ● | ● | | ● | | | | |
| FLAME CHEMISTRY & REACTION KINETICS | | | | ● | ● | ● | ● | ● | ● | | | | | | ● | ● | ● | ● | | | ● | | | | ● | | ● | ● | ● | ● | ● | ● | | | | | ● |
| QUANTUM EFFECTS | | | | ● | ● | ● | ● | | | | ● | | ● | | ● | ● | | | ● | ● | ● | | ● | | | | | | ● | ● | | | ● | | | | |
| GASEOUS REACTION KINETICS IN VACUUM | ● | ● | ● | ● | | | | | | | | | | ● | ● | ● | | ● | | ● | ● | | ● | | | | | | | ● | ● | ● | | ● | ● | | |

Figure 4-12. Basic Physics and Chemistry Laboratory Equipment

4.4 EARTH OBSERVATIONS

4.4.1 EARTH OBSERVATIONS FACILITY. The Earth Observations Facility goals are to utilize the unique capabilities of man in the orbital survey of the earth and its environment. They include: 1) defining the earth's geometry, surface characteristics,

and dynamic body properties, 2) understanding the physics of the atmosphere, the prediction of weather, and the establishment of a basis for weather modification and climate control, 3) responsible management of the earth's resources and the human environment.

The Earth Observations Facility, as shown in Figure 4-13, will include provision for data acquisition, sensor maintenance and repair, sensor control and display, and data analysis. Its function is to provide the means for making observations of the earth, utilizing the unique capabilities that man can provide to a laboratory in space. Summary requirement data are presented in Table 4-1.

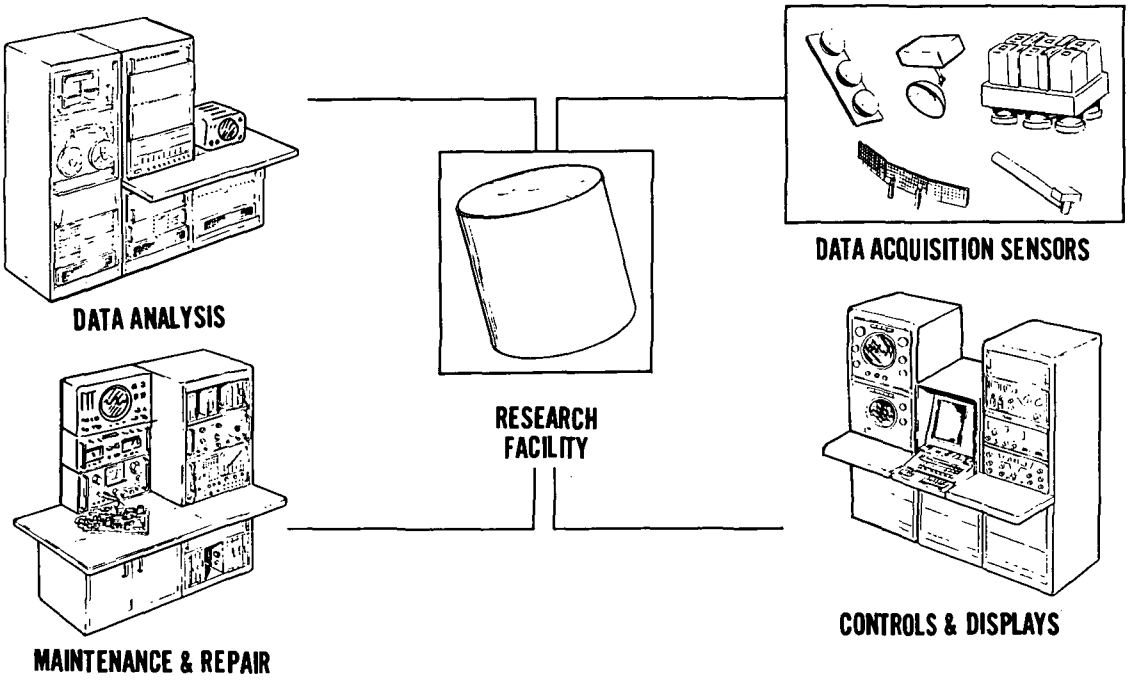


Figure 4-13. Earth Observations Facility

Research in both multisensor and multispectral sensing will be done, so provision must be made for operating sensors simultaneously without mutual interference. The facility design must be such that there is no obstruction in the field of view, and the sensors must be mounted so they are accessible to the crew for maintenance and modification.

Sensor controls and displays will monitor the sensors for proper operation and all raw data for electronic quality and selected data for quick-look evaluation. In addition to the usual on-off controls, there will be means to select level, frame rate, sequence etc. The data analysis equipment will involve the crew in data selection, management, and first-order analysis. Overall objective of the on-board analysis is to increase the quality of the data and to reduce the amount of redundant data sent to the surface. The

maintenance and repair unit will be used for calibration, repair, and modification of sensors and associated equipment. When new sensors are added to the facility, they will be received and prepared for use in this unit.

4.5 COMMUNICATIONS/NAVIGATION

4.5.1 COMMUNICATIONS/NAVIGATION RESEARCH FACILITY. The goals of this FPE are to facilitate continued and expanded application of space technology and satellite systems to better serve the national and international needs for communications with and between earthbound, airborne, and spaceborne terminals; and to improve continually the capabilities for terrestrial, air, and space vehicle navigation and traffic control.

Several continuing broad objectives guide the Communications/Navigation Research Facility in reaching its intended goals: 1) develop and demonstrate satellite systems and spacecraft technology applicable to space communications, navigation, and traffic control needs, 2) optimize the use of the electromagnetic spectrum of communications and navigation satellite systems, 3) provide fundamental understanding of the space communications and navigation sciences to permit NASA to fulfill its role as space communications and navigation consultant to government and industry.

Considering the activities to take place in the Communications/Navigation Research Facility, the following general groupings of activities are logical: 1) perform experiment to collect data; 2) examine data to evaluate experimental results; and 3) service experiment with various setup, calibration, and repair activities. Each activity is seen to employ types of equipments such that these may generally be grouped separately. The logical grouping of these activities leads to the "activity centers" and equipments of general use as indicated in Figure 4-14.

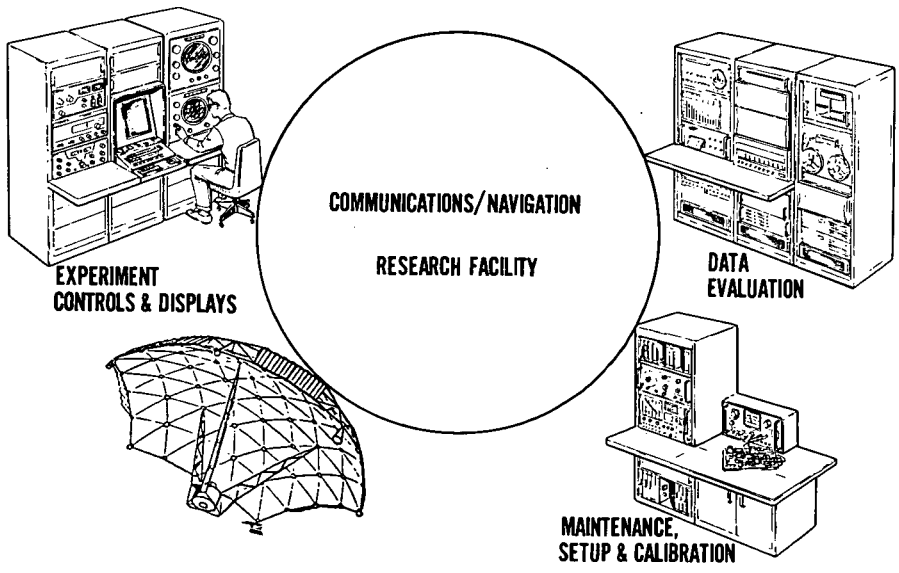


Figure 4-14. Communications/Navigation Research Facility

4.6 MATERIALS SCIENCE AND MANUFACTURING

4.6.1 MATERIALS SCIENCE AND MANUFACTURING IN SPACE. The objectives of this FPE are: (1) to provide the facilities and experimental techniques to accomplish a wide variety of research experiments and development work leading to the capability to manufacture materials in space, (2) to conduct a diversified program of space experimentation and related ground research during the 1970s which will define specific prospects for manufacturing in space and generate data for the ensuring materials and process development, (3) in the early 1980s, to develop specific processes to the point of commercial feasibility for manufacturing in space.

Materials science and manufacturing comprises a wide variety of materials, processing techniques, and potential products. This implies a considerable number of individual experiments, which have been classified into five major groups:

a. Metallurgical Processes - The objective is to produce metal products with superior properties, and unique new alloys. It includes a variety of metal-base composites, controlled density materials, contact-free processed alloys, supersaturated alloys, and slip castings.

b. Crystal Growth Experiments - These are primarily aimed at single crystals of large size, highest purity, and highest crystallographic perfection for advanced electronic, optical, and structural applications. This group further comprises a number of research experiments on solification phenomena.

c. Glass Processes - Objectives of this group are (1) exploration of the demonstrated feasibility to obtain, by contact-free processing, a variety of amorphous oxides, and (2) development of techniques for the production of new glasses with unique optical characteristics and base-materials for advanced semiconductors.

d. Biological Processes - The primary objective of this group is the electrophoretic separation and purification of biological materials, such as serums, viruses or microorganisms. It further includes the preservation of biological products by lypholization.

e. Physical Process in Fluids - This group comprises basic research experiments on phenomena in fluids which play a decisive role in the foregoing process applications, such as convection and other forms of fluid motion.

The approach adopted for the Materials Science and Manufacturing in Space (MS/MS) Experiment program is to plan payloads comprising assemblies of modular equipment items which can be used together in many different ways to perform the widest possible variety of experiments. The inventory of MS/MS payload equipment is designed for sufficiently general and flexible capabilities so that no experiment in the program's field will require any special apparatus beyond minor items of fixturing and instrumentation. This should enable the MS/MS experiment program to respond quickly to new possibilities and keep control of experiment costs. In addition, the modular approach can provide a basis for payload planning to cover a wide variety of mission options.

Summary data for the most significant MS/MS facility and operations requirements is presented in Table 4-1. Figure 4-15 illustrates several typical MS/MS equipment assemblies. The majority of experiments is carried out in one of the basic environmental chambers (shown in the illustration at left), which can be modified for specific experiments by the exchange of internal and external units. A special basic unit is the biological enclosure, consisting of the processing chamber and an air recirculation system. All experiments are controlled from the instrumentation and control center.

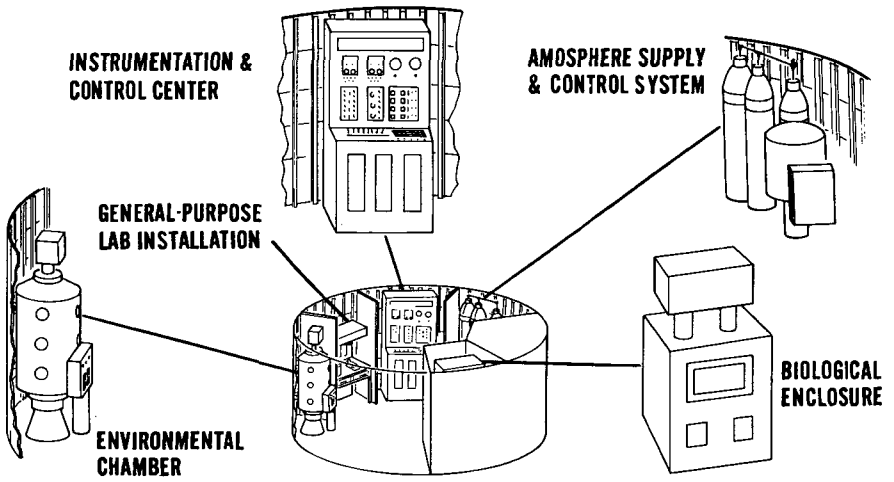


Figure 4-15. Materials Science and Manufacturing in Space

Figure 4-16 shows two other typical modifications of the basic environmental chambers. The chamber at the left is in open position for installation of a furnace unit. The chamber at the right is in operational condition for a free-casting experiment; the VHF power unit feeds the heating and positioning coil system, shown in the closeup of the high-temperature furnace unit above the apparatus. Two typical laboratory installations are illustrated at the top.

4.7 TECHNOLOGY

4.7.1 CONTAMINATION. The objectives of the experiments in this FPE are to: 1) monitor and trace the movement of external contaminants, 2) evaluate the light scattering effects of these contaminants on the performance of optical sensors, 3) measure the amount and effect of contaminants deposited on optical components, windows, etc. 4) evaluate techniques of removing the contaminants, 5) evaluate techniques for reducing the amount deposited and 6) evaluate active cleaning methods.

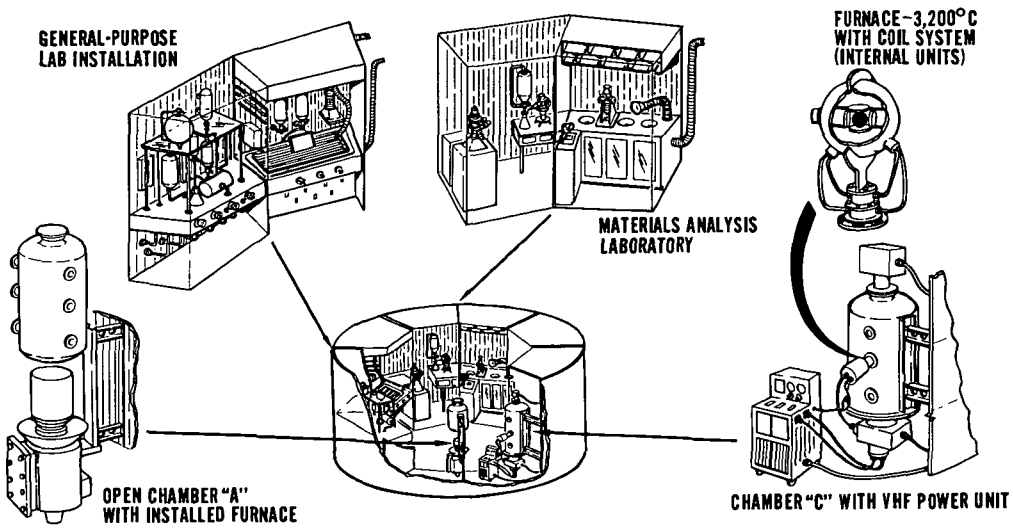


Figure 4-16. Materials Science and Manufacturing in Space

The experiment program includes a number of periodically scheduled observation periods and many random observations which may be required on short notice to support other experiments or to obtain engineering data on subjects of opportunity. Some of the observation programs require the simultaneous operation of several instruments. For each experiment, one instrument is indicated as the primary measurement means.

The facility concept is illustrated in Figure 4-17 wherein the individual experimental sensors require a common support capability consisting of power and data management subsystems, deployment means, and crew support.

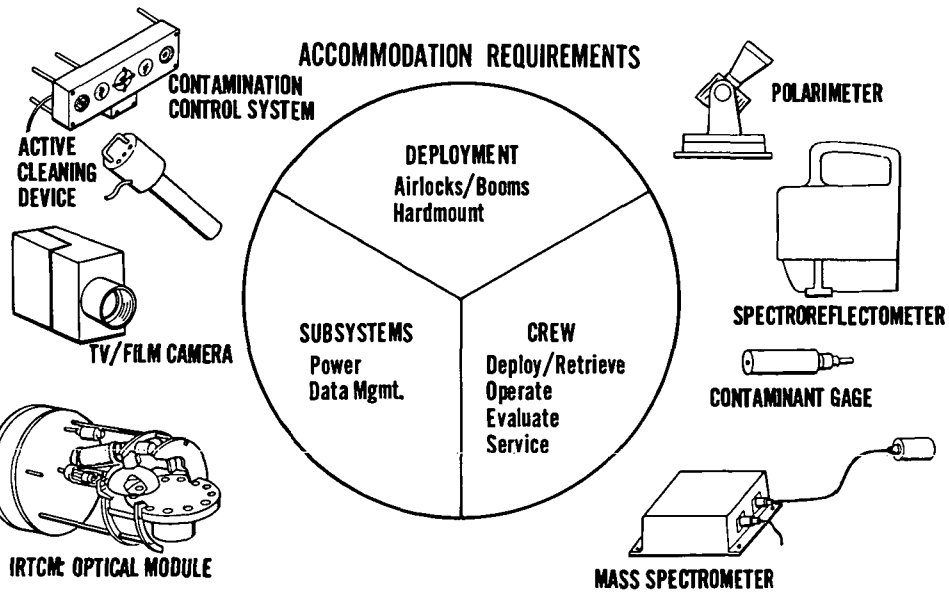


Figure 4-17. Contamination Measurements

Experiment deployment concepts minimize the need for EVA by employing airlocks for instruments which have use periods ranging from a few hours to a few days. However, for exposure apparatus which is deployed for periods ranging from weeks to years, EVA may be necessary for installing and retrieving the test apparatus and test samples.

The experiments can be accomodated as either Space Shuttle or Space Station payloads. The experiment equipment is of the "suitcase" type, and only requires a means of access to space, pointing and position means, and subsystems and crew support.

4.7.2 FLUID MANAGEMENT. Experiments included in the Fluid Management FPE are related to the understanding of fundamentals and optimization of design practices for advanced spacecraft fluid systems.

These experiments are designed to yield parametric information over the entire range of flows, temperatures, acceleration levels, heat transfer rates, etc., which may be encountered in future vehicle designs. Experiments which are science oriented (e.g., Critical State Phenomena and Zero-G Combustion) are contained in the Physics discipline.

Because these experiments establish unique and diverse facility environmental, and operational support requirements, summary data at the FPE level has not been derived. Instead the Experiment Requirements Summary Data is presented in Table 4-2.

To accommodate this FPE the systems designer may find it necessary to group and schedule experiment depending upon the capability of the supporting spacecraft to provide the necessary resources and controlled environmental conditions.

4.7.3 EXTRAVEHICULAR ACTIVITY. The two experiments included in the FPE describe the development and evaluation of an Astronaut Maneuvering Unit (AMU) and a Maneuverable Work Platform (MWP). These experiment may be accommodated either as Space Station or Shuttle-sortie payloads.

The Maneuvering Work Platform (MWP), Figure 4-18, is an open-structure, hydrazine-propelled vehicle, with variable cargo-bed geometry. The vehicle consists of two modules, one forward and one aft. The forward module contains propulsion/ACS thrusters, flight controls and displays, EC/LSS, electrical power, and communications subsystems. The aft module contains propulsion/ACS thrusters and an extendable antenna.

Typical uses for the MWP include the orbital assembly of large structures, cargo transfer, and transportation of crewmen, tools, and spare parts for EVA maintenance activities.

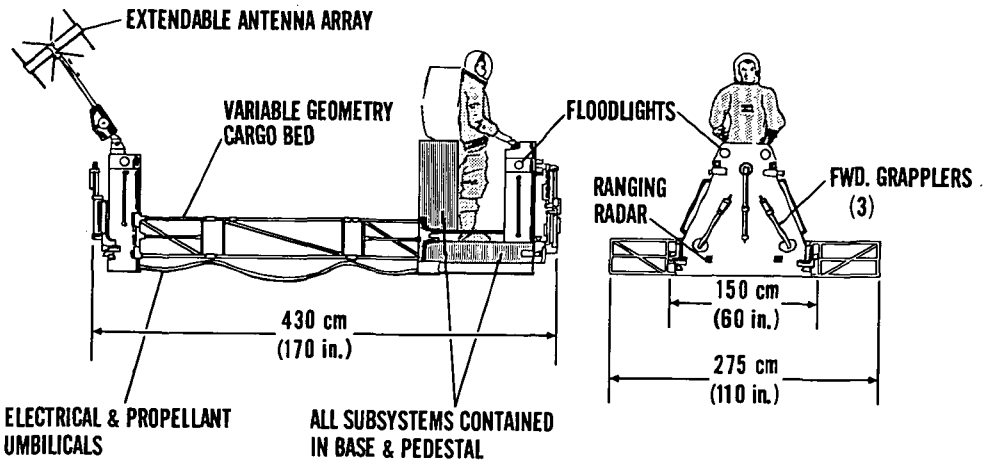


Figure 4-18. Maneuverable Work Platform

The Astronaut Maneuvering Unit (AMU), Figure 4-19, is an individual EVA mobility aid which is an advanced version of the M-509 experiment. The AMU is a back-mounted unit which provides life support, propulsion, attitude control, and communications functions. This experiment is one phase of an orbital test program for AMU development and evaluation.

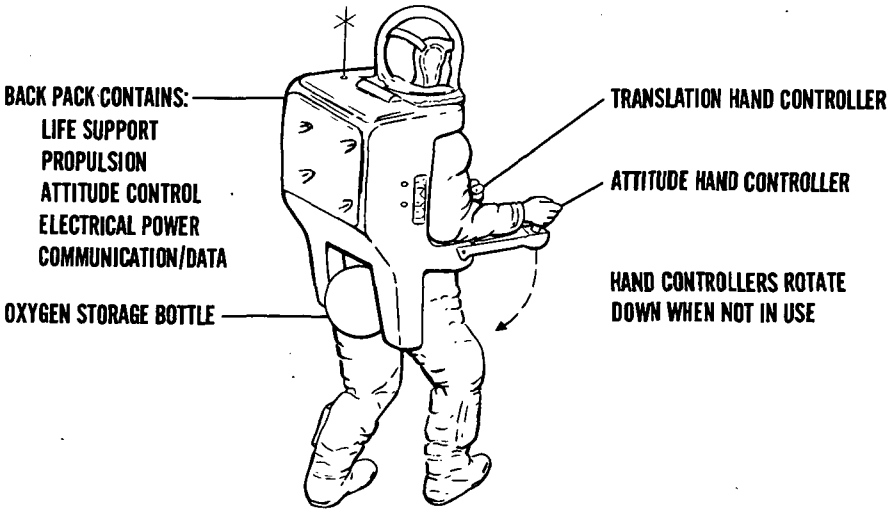


Figure 4-19. Astronaut Maneuvering Unit

4.7.4 ADVANCED SPACECRAFT SYSTEMS TESTS. This FPE describes typical types of tests that will be performed in orbit to develop and qualify hardware for future spacecraft. The summation of test support requirements determines the design criteria for a General-Purpose Laboratory (GPL) in space.

Analysis of the experiment requirements indicates a large measure of commonality in the need for support items such as airlocks, stabilized platforms, deployment booms, test cells, and instrumentation. A relatively small number of multipurpose support items will be incorporated in the GPL for widespread use. Specialized support equipment, as well as experimental devices, will be treated as "suitcase" payloads. Typical "suitcase" experiments are illustrated in Figures 4-20 and 4-21.

Summary data for this FPE are presented in Table 4-1.

4.7.5 TELEOPERATIONS. The goal of this FPE is to develop and evaluate an experimental teleoperator system for use with future space activities. Such a system would be a precursor to an operational system and would provide a means for evaluating teleoperator system performance and applications.

The means for providing this evaluation will be a series of experiments designed to provide a systematic basis for the evaluation task. Upon completion of this experimental phase, the system would be converted to an interim operational EVA tool for use by Space Shuttle or Space Station while final design of a fully operational system was being completed.

The experimental teleoperator (T/O) system, as shown in Figure 4-22, is comprised of a small, free-flying T/O spacecraft and a control station. A two-way RF link provides commands to the T/O spacecraft and feed-back information to the control station. The control station may be located in a parent spacecraft or in a ground installation.

The T/O manipulator arms duplicate the motions of a human controller operating the master manipulator at the control station. A steroscopic TV system and manipulator force feed-back provide the controller with a feeling of presence at the T/O work site. Summary data is presented in Table 4-1.

4.8 LIFE SCIENCES

The NASA Life Sciences Program encompasses all of the individual program areas covering operational and medical questions associated with manning and operating an Earth orbital research facility or facilities; the development, testing and incorporation into such facilities the advanced technology for life support and protective systems;

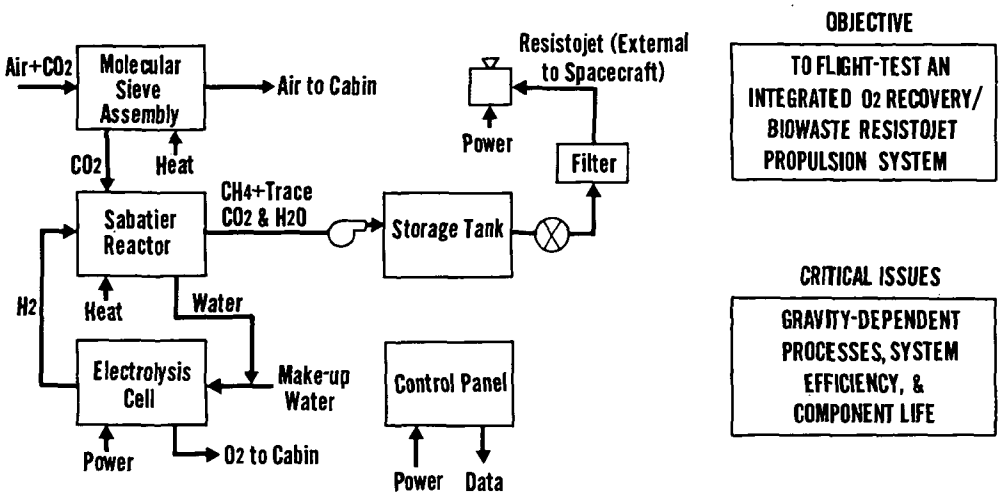


Figure 4-20. Biowaste Resistojet Propulsion System

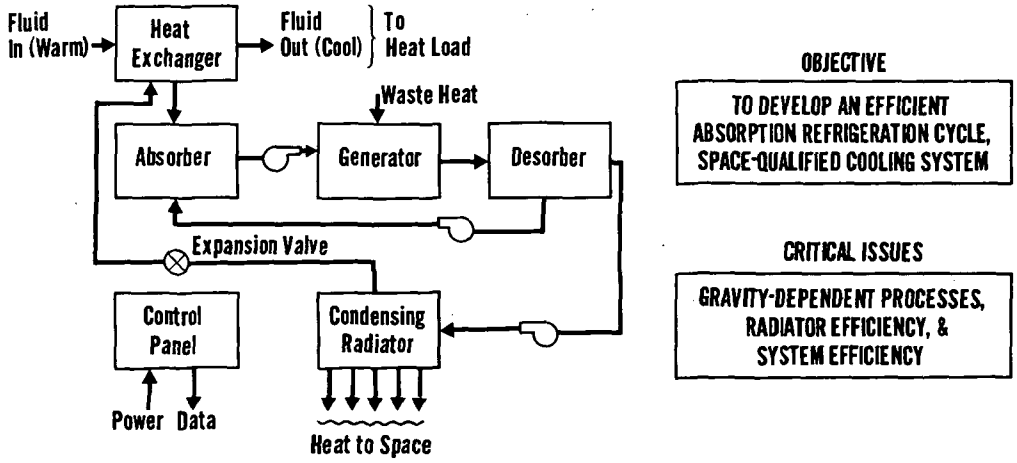


Figure 4-21. Refrigeration System Schematic

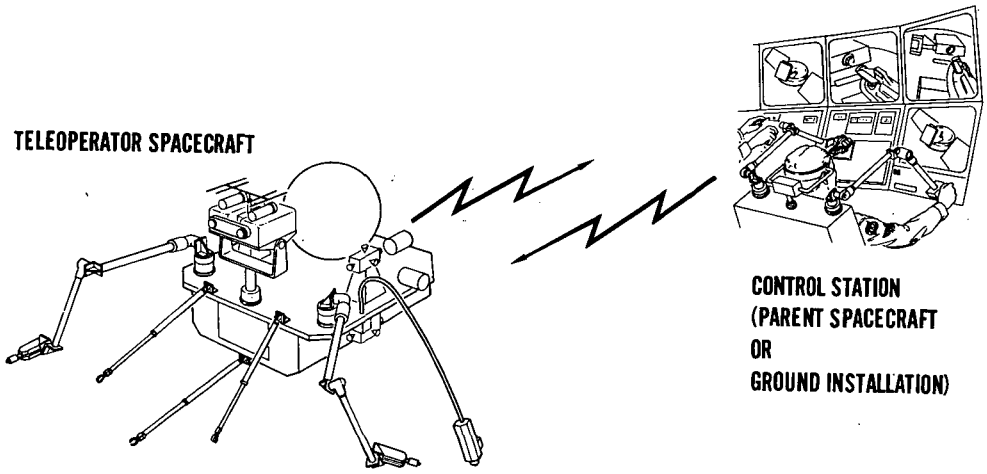


Figure 4-22. Teleoperation

and fundamental biological and biomedical research. This discipline contains the following FPEs:

Medical Research Facility	Cells and Tissues Research Facility
Vertegrate Research Facility	Invertebrate Research Facility
Plant Research Facility	Life Support and Protective Systems
	Man-System Integration

The program as defined is a "candidate" program. The individual experiments identified are thus not necessarily the precise experiments that ultimately will be conducted They are, however, representative examples of the types of research activities that will be carried out.

The most effective pursuit of this program depends upon a life sciences space laboratory consisting of: 1) an overall core of facilities and instrumentation (CORE) serving a broad spectrum of experimental areas in several FPEs, 2) supplemental facilities and instrumentation relating to a smaller number of FPEs or experiments but which are sufficiently specialized to be removed from the core, and 3) FPE or experiment peculiar items ancillary to one or both of the preceeding more general categories.

The composition of the CORE is defined by commonality of equipment among all of the FPEs as illustrated in Figures 4-23 and 4-24. As indicated any particular research facility may be constructed utilizing the CORE plus the necessary special purpose and/or experiment peculiar equipment. The radiobiology unit and the bioresearch centrifuge, although common to most FPE requirements, are not included in the current CORE but are considered as growth items.

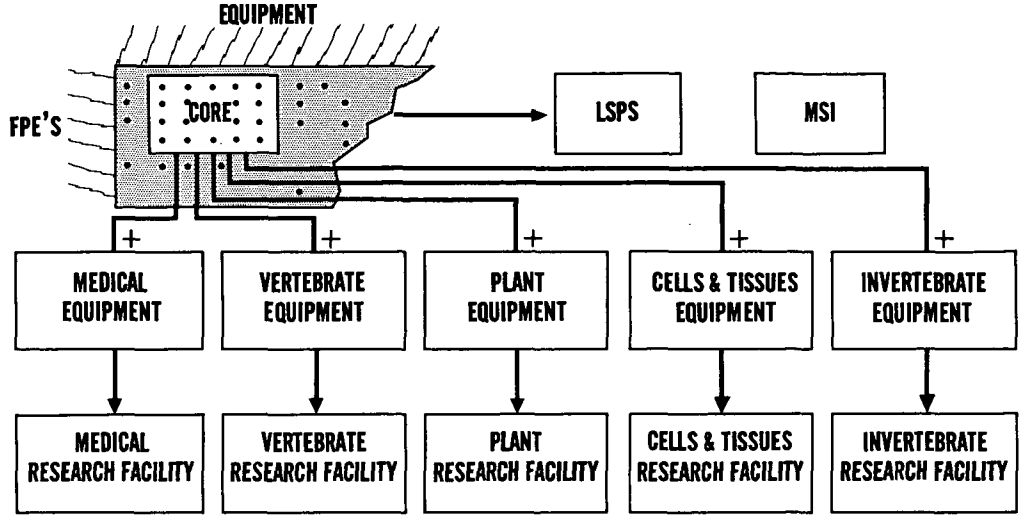


Figure 4-23. Life Sciences Facility Approach

A few equipment items representative of CORE units for analysis, measurements, and data are illustrated in Figure 4-25. The Biochemical/Biophysical Analysis Unit has capabilities in biochemistries, histochemistries, hematology, mass spectrometry, gas chromatography, electrophoresis, spectrophotometry, and others needed in Life Sciences. The Visual Records and Microscope Unit capabilities include still photography, cinematography, television, hard records, oscilloscopic display/readout, electronic imaging, microscopic observations and records, micromanipulation, and microscope dissecting. The Data Management Unit functional capabilities include data storage, experiment management, subsystem control, electrophysiological and electromechanical transducer support, signal analysis and display, and crew experiment task guidance.

The service units of the CORE are represented in Figure 4-26. The Life Sciences Experiment Support Unit has the primary function of a supply and services interface between the space vehicle and Life Sciences experiments. It provides for transfer, distribution, control, and conditioning as required for electrical and fluid utilities, including: electrical power, hard line data transfer, vacuum, water, purge and pressurant gases, process gases, thermal control fluids, and time signals, alarms, and other special communications. The Preparation, Preservation, and Retrieval Unit capabilities include specimen autopsy, sample preparation, sample fixation, histological sectioning, bacteriological and histological staining, microbiological sampling and transfer, organism preservation, specimen preservation, substrate preparation, sterilization, cleaning, and chemical storage and handling. The Maintenance, Repair, and Fabrication Unit is for instrument cleaning, repair and checkout, apparatus maintenance, modification and fabrication, and cage cleaning. The Ancillary Storage Unit provides some general storage and some which is specific for designated instruments and accessories.

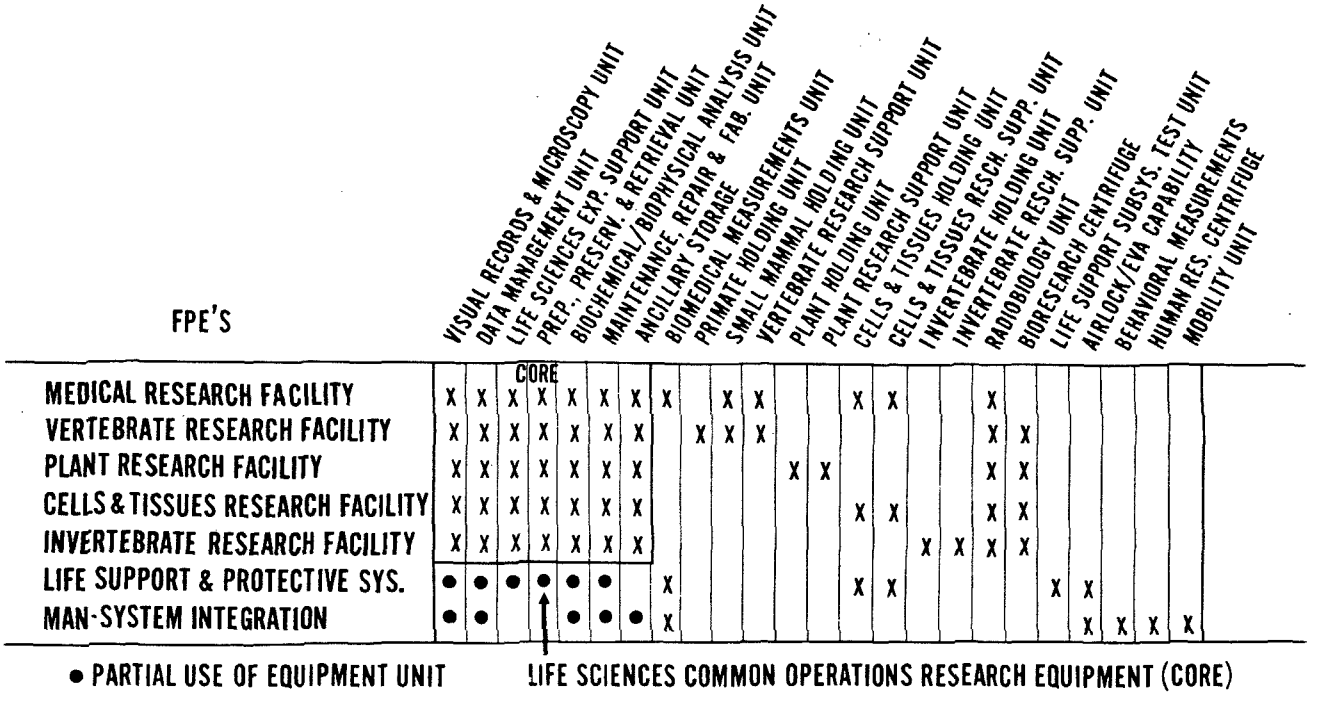


Figure 4-24. Life Sciences Equipment Units

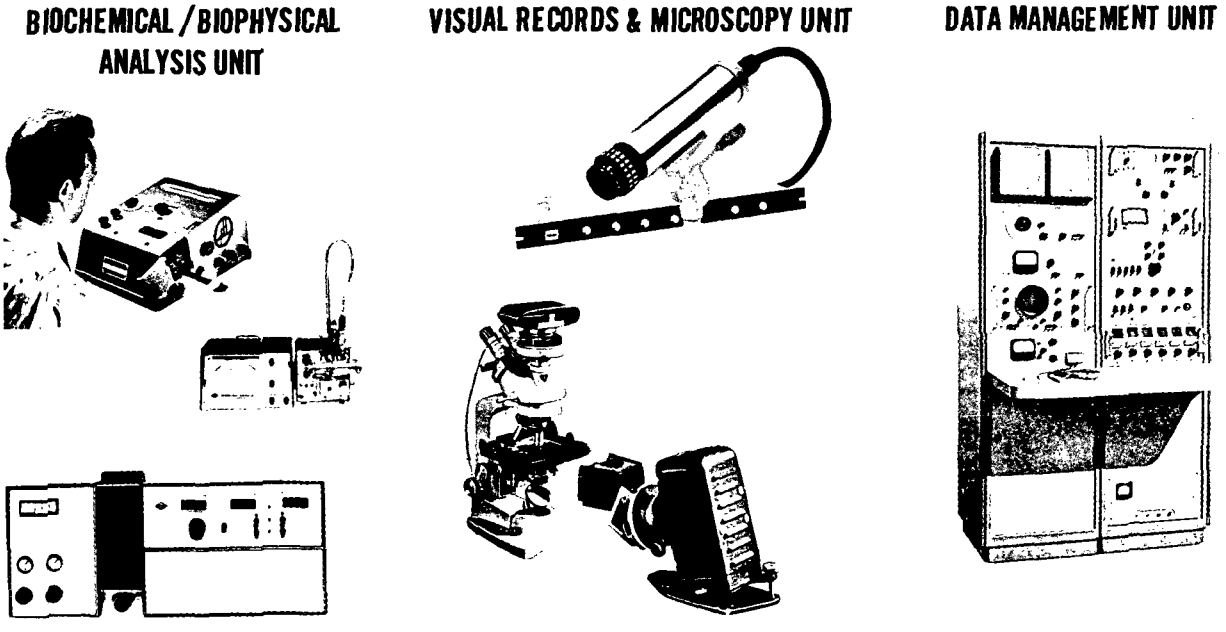


Figure 4-25. Life Sciences CORE: Analysis, Measurements and Data

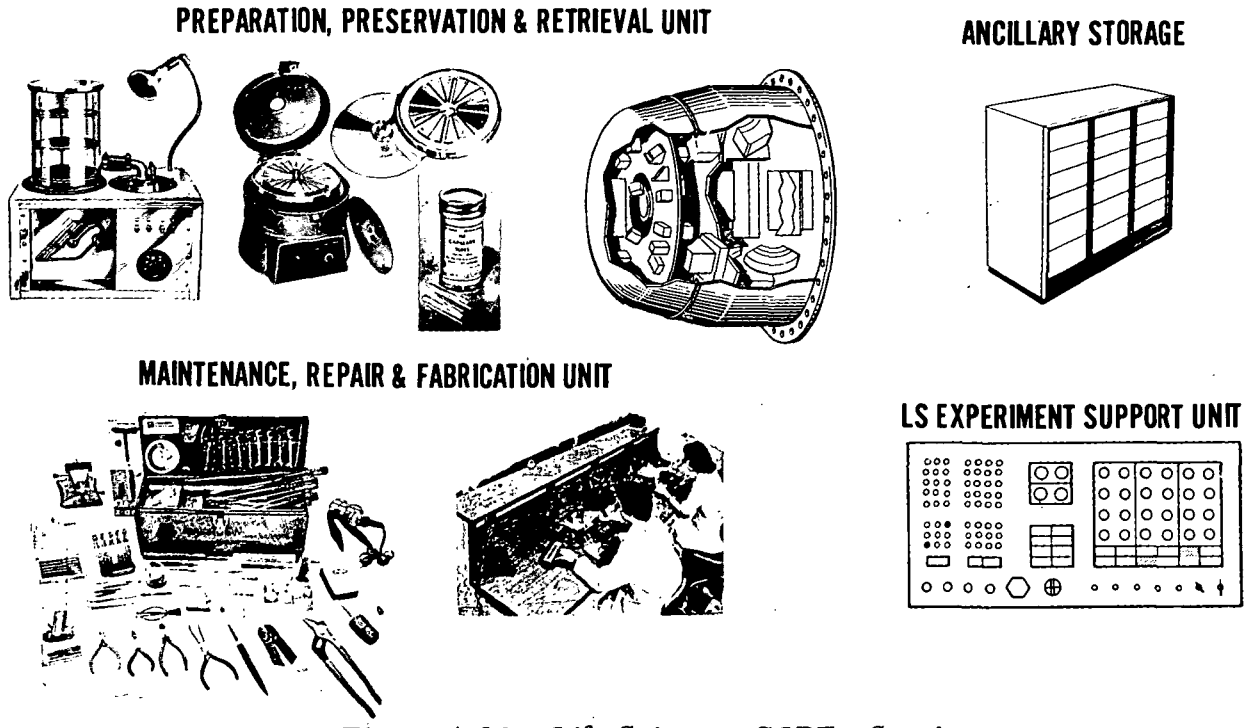


Figure 4-26. Life Sciences CORE: Services

4.8.1 MEDICAL RESEARCH FACILITY. Medical experiments will be devoted to the evaluation of changes in human function and capabilities which may be induced by long-duration space flight. The goals shown are oriented toward the support and enhancement of man and his abilities in manned space flight. There is an additional objective of obtaining scientific information of value to conventional medical research and practice.

The total facility requirements for this FPE are illustrated in Figure 4-27. Equipment specific to this FPE comprises the Biomedical Measurements Units and its peripheral units, which are the body mass measurement device, the lower body negative pressure device, the bicycle ergometer, and the rotating litter chair. The unit provides the instrumentation needed to interface the human subject with the medical experiments for those measurements which are not included in the CORE Facility. In general the instrumentation services more than one experiment and includes transducers and other devices which interface with the subject directly — sensing electrical signals, rates, flows (e.g., ECG, EMG, pulmonary flow meter), and other measurements to support medical research in the areas of neurology, cardiovascular physiology, and respiration and metabolism. Additional support in the areas of blood and urine analysis, microbiology, histology, and bioassays is provided by the CORE. The summary data is presented in Table 4-1.

4.8.2 VERTEBRATE RESEARCH FACILITY. The Vertebrate Research Facility will permit a broad spectrum of specific and general experiments in support of the goals and objectives in space biology:

a. To understand the role of gravity in life processes and the capability of living organisms to adapt to gravitational changes.

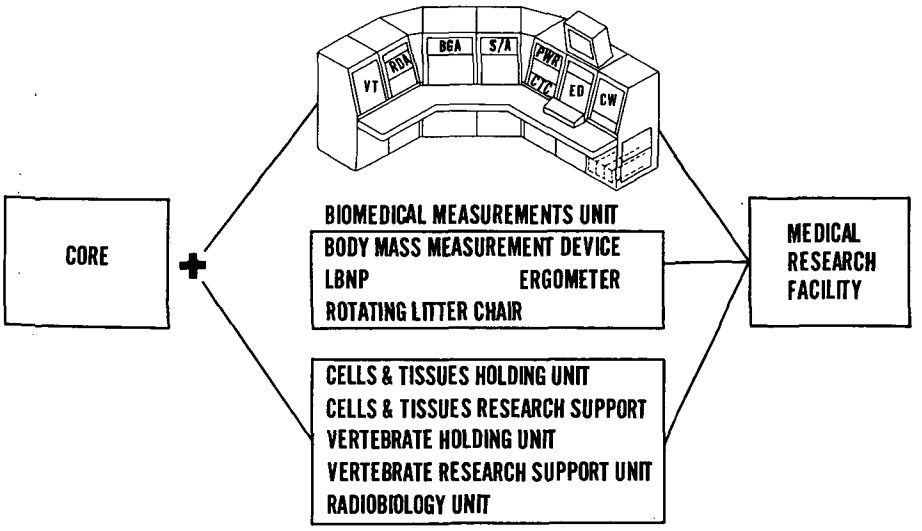


Figure 4-27. Medical Research Facility

b. To understand the role of time in biology, including the effects of time-varying environmental parameters on biological rhythms and aging.

c. To determine the potential applications and develop the techniques to utilize advances in theory and space technology to advance medicine, biology, public health, agriculture, and space exploration. The facility provides holding and rearing accommodations as well as research instrumentation for a wide variety of vertebrates. The rearing accommodations will permit establishing a "weightlessness adapted" strain of animals considered essential in studying adaptive processes.

As in other FPEs of Life Sciences, the facility, as illustrated in Figure 4-28, comprises the CORE, additional FPE-specific equipment units, and equipment units shared with other FPEs but not part of the CORE. The FPE-specific units are the Small Mammal Holding Unit, the Primate Holding Unit, and the Vertebrate Research Support Unit. The holding units provide for four primates, 256 rats, or equivalent capacity for quail, hamsters, marmots, or other animals.

Lesser capacity is acceptable for selected experiments. The primate holding units are five-foot spheres with a three-foot hatch. The small-mammal holding units are cage racks with several sizes of cages for the various animal specimens. Functional capabilities of the Vertebrate Research Support Unit include EEG, EMG, thermal measurements, gas measurements, ergometry, and camera systems.

The Radiobiology Unit will provide facilities for irradiating biological specimens to investigate the interaction of radiation and weightlessness on the radiation-induced injury process, recovery, chromosomal aberrations, somatic and genetic mutations, performance, and behavior. The facility includes: 1) radiation exposure room, 2)

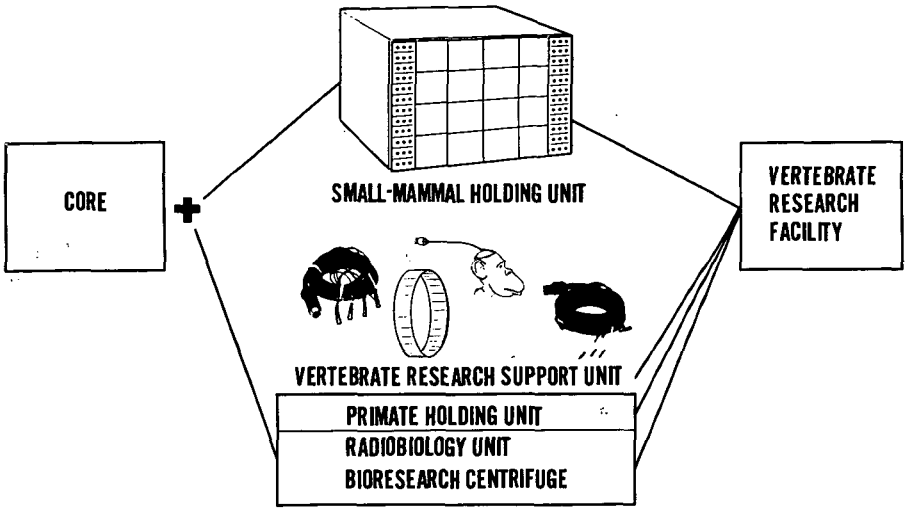


Figure 4-28. Life Sciences Vertebrate Research Facility

the gamma isotope radiation source, 3) radioisotope storage unit, 4) radiobiology laboratory to be used for injecting radioisotopes and counting radioactivity in samples or whole specimens, and 5) diagnostic X-ray unit.

The Bioresearch Centrifuge has functions of: 1) inflight one-g controls, 2) controlled graded levels of acceleration to establish thresholds of response to acceleration, and 3) determining the degree and reversibility of deconditioning, or conversely, determining the rate of readaptation of organisms to acceleration. The centrifuge has cage racks like those in the main laboratory. Their positions at various radii provide the graded levels of acceleration.

4.8.3 PLANT RESEARCH FACILITY. The program in Plant Research covers the effects of space environment (weightlessness, subgravity, ionizing radiation, etc.) on all major aspects of plant biochemistry, physiology, and genetics. Particular emphasis is placed on morphology, growth, development, maturation, longevity, reproduction, and cyclic phenomena. Experiments will encompass photographic histories from sprouting through to death, microscopic examinations of cells and tissues, and biochemical analyses for composition and distribution of enzymes, hormones, metabolic substrates, and synthesized plant products.

As illustrated in Figure 4-29, the total facility consists of the CORE, the FPE-specific Plant Holding Unit and Plant Research Support Unit, and the Radiobiology Unit and Bioresearch Centrifuge which are shared with other FPEs. The Plant Holding Unit is a rack and module system standardized with other holding units in the biology group of FPEs. It will house a wide variety of plants from microscopic specimens to plants 20 centimeters tall. The Plant Research Support Unit consists of equipment and accessories for plant research, including plant lighting, photo/TV coverage, time identification, specimen identification, specific ion analysis, growth measurements, activity

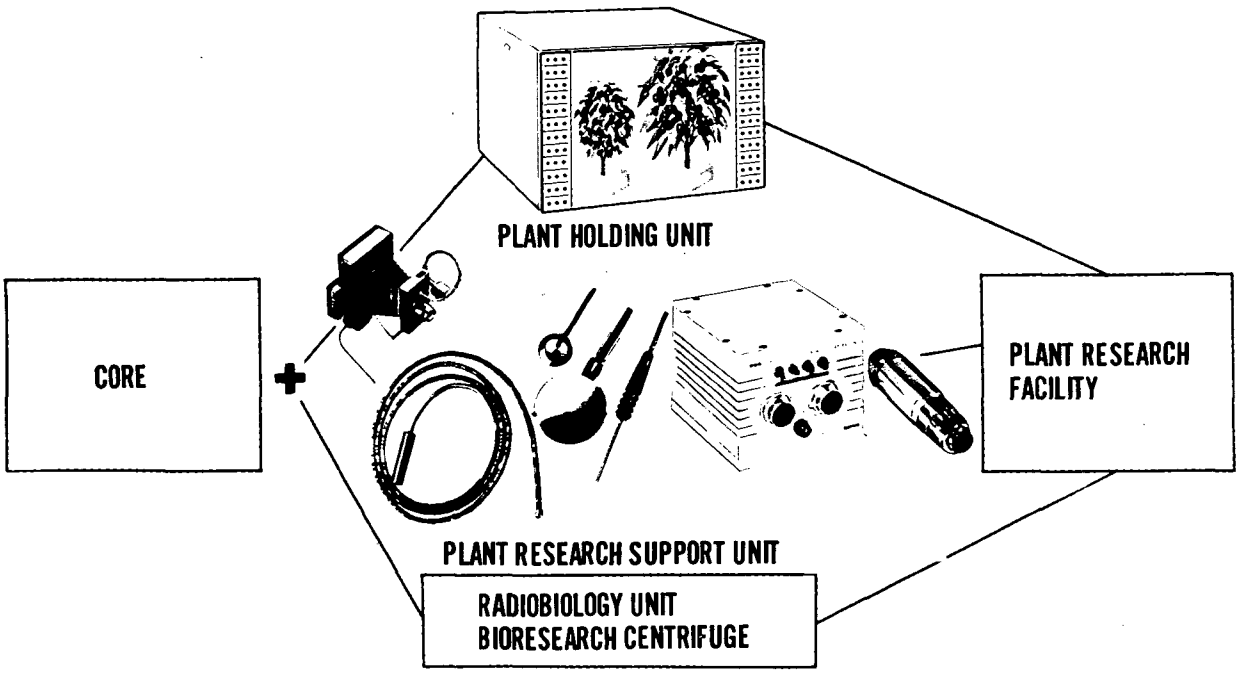


Figure 4-29. Plant Research Facility

measurements, water and nutrients management, water and nutrients sampling, event verification, and clinostats. Summary data requirements for this FPE are presented in Table 4-1.

4.8.4 CELLS AND TISSUES RESEARCH FACILITY. The research to be supported by this FPE includes a study of the growth, reproduction, morphology, biochemistry, and genetics of a variety of single-celled organisms and tissues in culture. Some of the objectives are evident in the titles of the experiment classes. In more detail, the objectives include: discerning the role gravity plays in the cellular functions of growth and replication: discerning whether cultured cellular and tissue development, structures, and function are altered by the space environment; observing variation in adaption in the space environment; developing the capability to predict extent of cellular variability as a function of time in the space environment; establishing whether the space environment significantly alters the genetic coding mechanisms; describing the interaction of the environment with subcellular structure and function; investigating biochemical phenomena; and investigating environmental factors in control of rhythmic phenomena by the removal of these factors.

Figure 4-30 illustrates the facility requirements of this FPE. The FPE-specific units are the Cells and Tissues Holding Unit and the Cells and Tissues Research Support Unit. The first serves to hold and support microorganism and cell culture stock and research organisms. It is basically a series of incubators mounted at various temperatures, which will support observation, sampling, gas analysis, and other measurements. The Cells and Tissues Research Support Unit provides an inventory of supplies and transducers required to accomplish cells and tissue research. Representative items are culture containers (dishes, vials, bottles, and test tubes), assorted dehydrated substrates or prepared substrates, and specimen transfer devices (probes, loops, and pipettes).

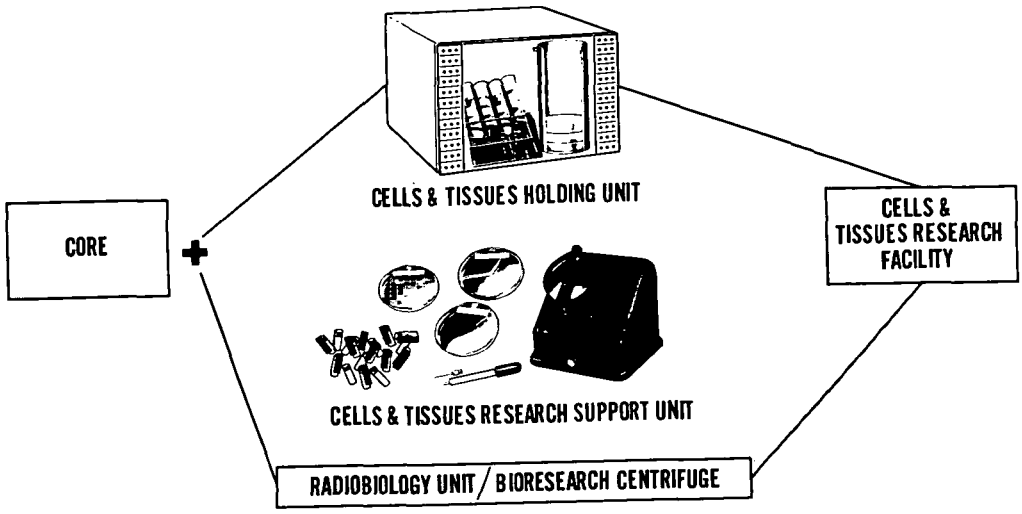


Figure 4-30. Cells and Tissues Research Facility

4.8.5 INVERTEBRATE RESEARCH FACILITY. The objectives are generally the same as stated for other biology FPEs except that they are applied to invertebrates. In more detail, these objectives are to detect, quantify, and determine the mechanisms of alterations in the basic life processes of invertebrates exposed to weightlessness; to detect, quantify, and determine the mechanisms involved in the modification of invertebrate behavior by exposure to the space environment; and to detect modifications in the genetics of invertebrates and discover the mechanisms underlying these changes.

The Invertebrate Holding Facility, Figure 4-31, contains enclosures for the various specimens, consisting of a rack assembly which will hold slide-in experiment packages. Because of different temperature requirements, packages will be grouped in sections according to these requirements. Each such section will have independent temperature control. The Invertebrate Research Support Unit contains all the specific tools, containers, and transducers required for invertebrate research. The capabilities are: camera optics specific for invertebrates, special holding cages (e.g., for flys, bees, cockroaches), microrespirometers, flight chambers, invertebrate transducers, and eclosion rate monitoring.

4.8.6 LIFE SUPPORT AND PROTECTIVE SYSTEMS. The objective of Life Support and Protective System (LSPS) technology is to provide a controlled and physiologically acceptable environment for flight crews during all phases of a space mission. The objective of this FPE is to provide critical information of human environmental requirements, the design criteria for LSPS, and the technology which will enable men to perform future space missions effectively and in safety.

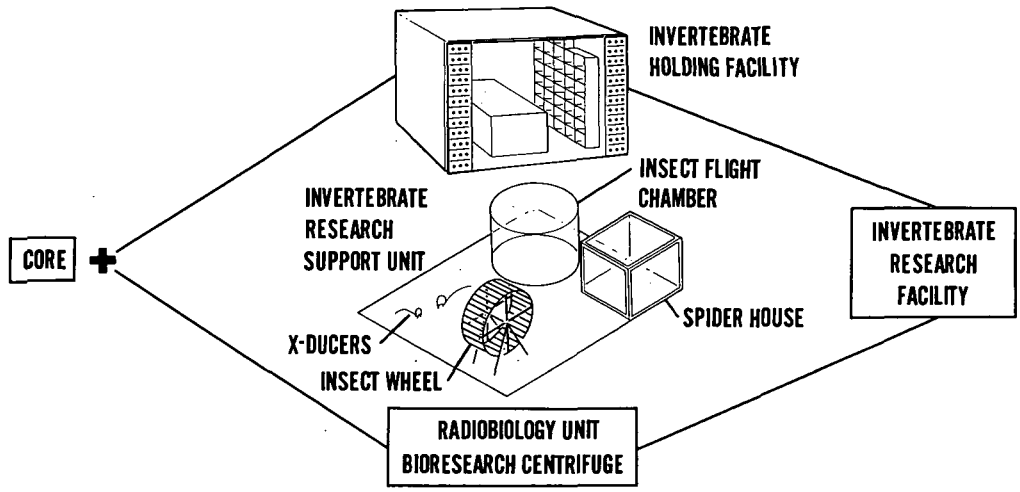


Figure 4-31. Invertebrate Research Facility

As indicated above, the LSPS facility, Figure 4-32, utilizes only portions of the CORE units. The Life Support Subsystems Test Unit provides utilities, controls, and instrumentation which are common to life support experiments. It will accept for experimental operation at least one experimental component, assembly, or subsystem, which may have additional controls and instrumentation that are experiment-peculiar. The unit will provide connections for the test assembly to utilities, including electrical power, pressurant gas, purge gas, process gases, vacuum, and heat transport fluid supply and return. Manual operating capability will include on-off controls and flow modulation of gases and heat transport fluid.

The Airlock/EVA Capability Unit provides the crew with the capability for egress and EVA. Functions include passage from within the vehicle to the space environment without disturbing the interior environment, life support while in the EV environment, restraint from drifting free of the spacecraft, illumination as required, and crew monitoring of the EVA subject.

4.8.7 MAN-SYSTEM INTEGRATION. The goals and objectives in Man-System Integration (MSI) are related to the experiment classes: Behavioral Effects; Performance Capability; Habitability and Proficiency; and Rotogravitation. Behavioral effects include those experiments designed to determine the effects of prolonged exposure to the spaceflight environment on man's individual and group behavior. The performance capability assessment class is designed to evaluate man-system performance capabilities in the space-flight environment. The habitability and proficiency maintenance class is designed to evaluate man-system characteristics that maintain and/or prevent degradation of that performance. The rotogravitation experiments are designed to evaluate man's behavior and performance capabilities in artificial gravity.

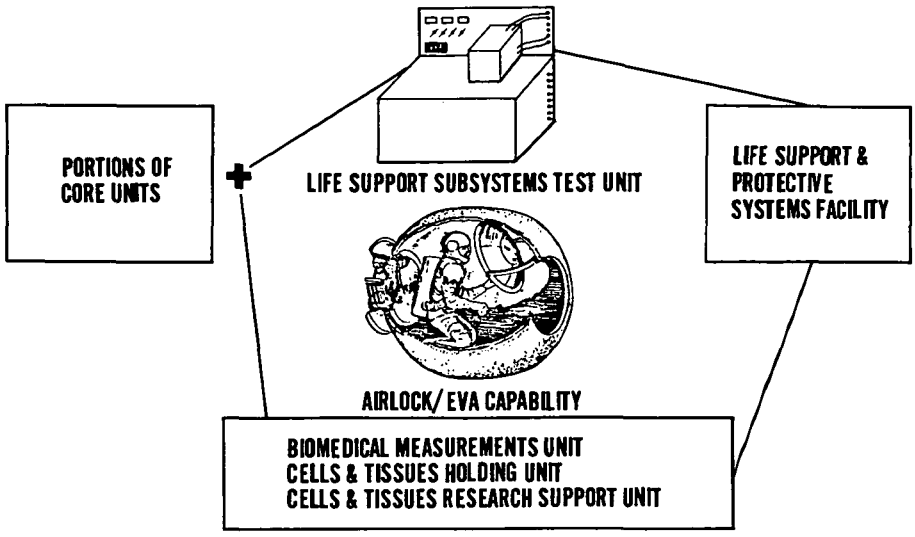


Figure 4-32. Life Support and Protective Systems

The MSI facilities also require only portions of the CORE units as indicated in Figure 4-33. The Behavioral Measurements Unit has capabilities for measurement of sensory, psychomotor, and complex processes. Sensory measurements include visual (depth perception, brightness threshold, visual field, flicker fusion frequency, phorias, acuity, glare recovery, color perception), auditory (absolute threshold, pitch discrimination, temporal acuity, speech intelligibility), and cutaneous. Psychomotor measurements include fine motor abilities, complex motor abilities, gross body coordination, and reaction time. Complex processes include time and motion, complex perceptual processes, mediational processes and memory processes.

The Mobility Unit consists of a portable metabolic analyzer and impact detector system, portable accelerometers, an event timer, and certain restraints and location aids. Their function is to measure parameters associated with man's locomotion and stabilities.

The Human Research Centrifuge has an experiment chamber which encloses all experiment activity. It has a television monitoring system and two-way voice communication between experimenter and subject. The walking floor and various experiment kits support experiments in locomotion and balancing, fine psychomotor capabilities, and cargo handling in rotogravitation.

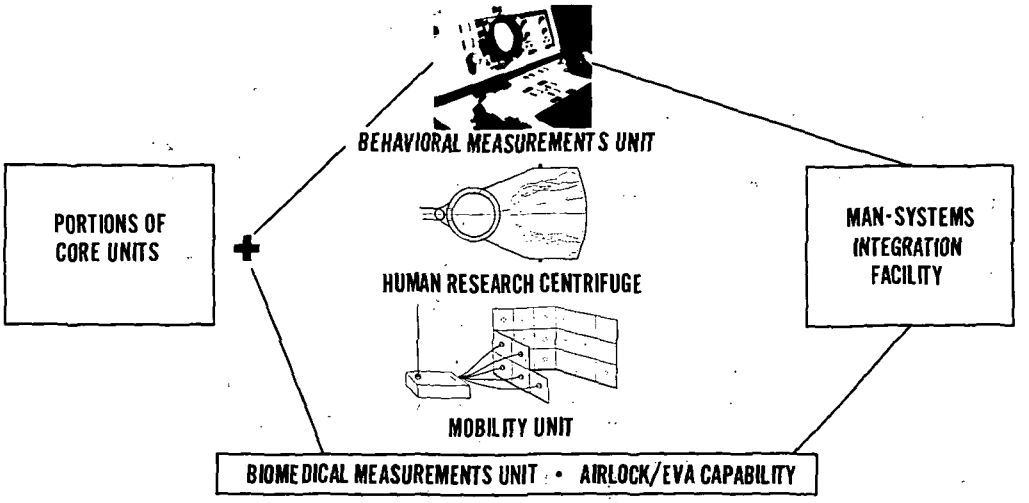


Figure 4-33. Man-Systems Integration